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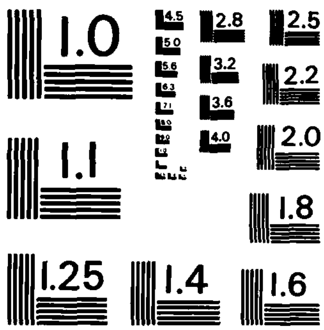

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THE EFFECT OF LONGITUDINAL CENTER OF FLOTATION
AND LONGITUDINAL METACENTRIC HEIGHT ON RESPONSES
OF LOW SPEED SWATH CONFIGURATIONS

by
K.K. McCreight

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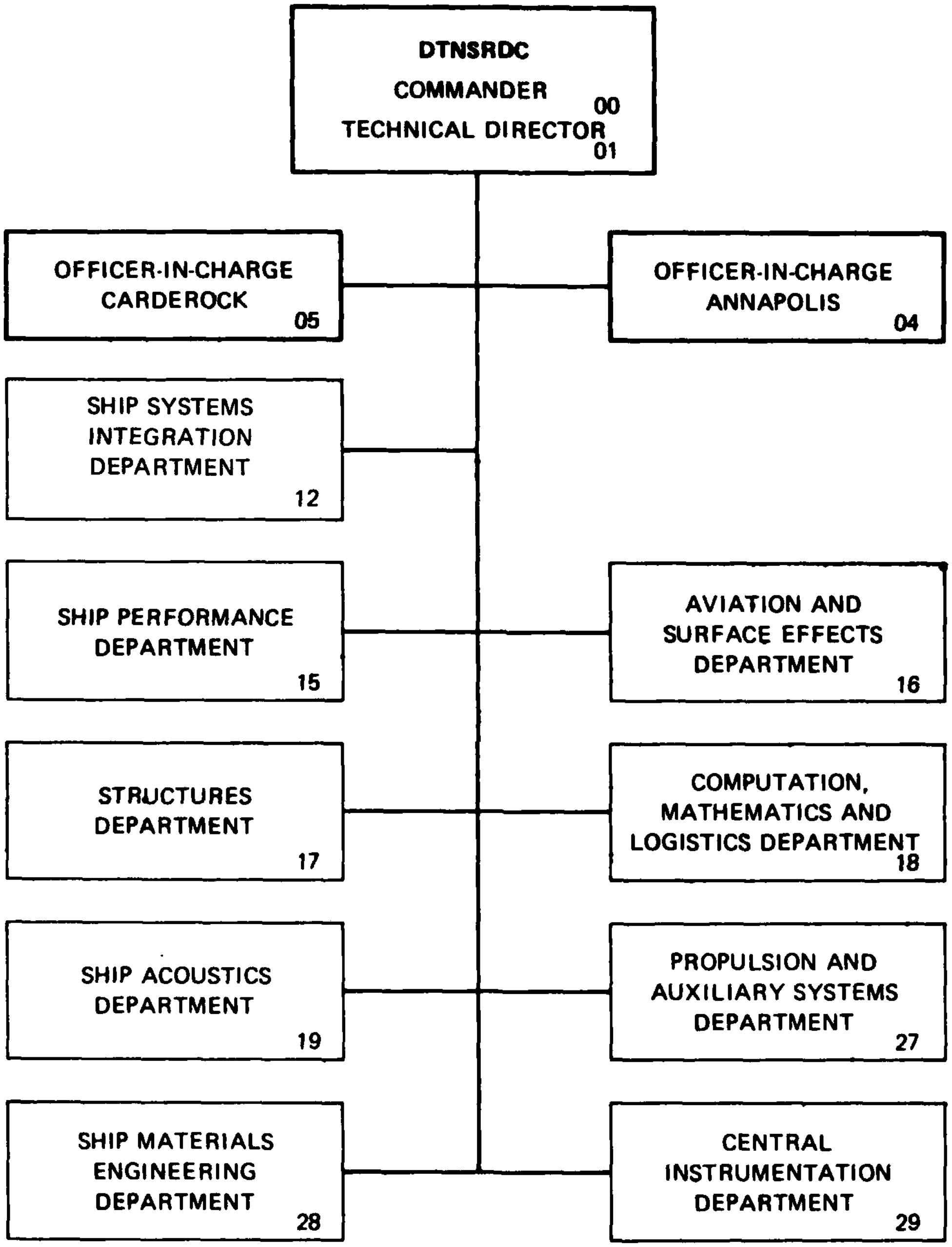

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The effect of longitudinal metacentric height (GM_L) and longitudinal center of flotation (LCF) on responses in regular waves and irregular seas is investigated analytically for a series of 2550 tonne SWATH configurations. All configurations have two struts per hull and lower hulls which include conic frustrums. Heave, pitch, relative bow motion, absolute bow motion, and absolute stern motion are studied at 0, 3, 10, and 15 knots in head and following seas. The predictions show that increasing GM_L generally results in decreased responses to irregular seas. Locating the LCF aft of the longitudinal center of buoyancy (LCB) in head seas reduces responses for all motions studied for low speeds and in following seas reduces relative and absolute vertical motions at the bow for all speeds.

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ABSTRACT

The effect of longitudinal metacentric height (GM_L) and longitudinal center of flotation (LCF) on responses in regular waves and irregular seas is investigated analytically for a series of 2550 tonne SWATH configurations All configurations have two struts per hull and lower hulls which include conic frustrums and a large-diameter cylindrical section. Heave, pitch, relative bow motion, absolute bow motion, and absolute stern motion are studied at 0, 3, 10, and 15 knots in head and following seas. The predictions show that increasing GM_L generally results in decreased responses to irregular seas. Locating the LCF aft of the longitudinal center of buoyancy (LCB) in head seas reduces responses for all motions studied at low speeds and in following seas reduces relative and absolute vertical motions at the bow for all speeds.

ADMINISTRATIVE INFORMATION

This study was sponsored by the Naval Sea Systems Command, Code 03RD under the CONFORM program and was administered by the SWATH Ship Development Office, Code 117, of the David Taylor Naval Ship Research and Development Center, under Program Element 63564N, Task Area S0408069, Work Unit Number 1170-123.

INTRODUCTION

The SWATH configuration provides the ship designer with the opportunity to design ships with optimum seaworthiness characteristics for a particular application. Although mission requirements determine many characteristics of the hullform, some details are flexible. For example, stability requirements determine the waterplane area for a given hull spacing. Machinery requirements will determine certain physical boundaries. However, even with such specifications many hullforms are possible. In particular, the strut shape frequently can be altered without affecting the applicability of a design to a mission. Changing strut shape can change longitudinal metacentric height (GM_L) and longitudinal center of flotation (LCF). Such changes can be made to a SWATH without changing the shape of the lower hull or the dimensions of the main deck. Similar changes to characteristics of conventional surface ships would require major alterations of the hull and, therefore, of the internal arrangements.

Previous analytical studies, including the one described in reference 1*, have shown that GM_L and LCF can have a notable effect on a SWATH's responses to waves. Since motions are sensitive to these characteristics it is important to understand the effect of these variables on motions.

This study explores ranges of values of GM_L and LCF. A baseline form and configurations with three variations of GM_L and four variations of LCF are systematically generated so that several other key characteristics, such as length and draft, are fixed. All configurations have two struts per hull and displace approximately 2550 tonnes. The configurations have bulbous bows and "shaped" lower hulls. That is, the lower hulls are formed from conic frustrums and cylindrical sections. Although this shaping is not expected to be as important to motions as the hydrostatic characteristics, the shaping is important to resistance, particularly for tandem strut SWATH configurations. Resistance considerations guided the selection of geometric characteristics of these configurations. For example, the values of characteristics such as the diameter of the bulbous bow relative to the midship diameter and the strut taper affect resistance.

Stabilizing fins are incorporated in each configuration. Heave, pitch, relative bow motion, absolute bow motion, and absolute stern motion in head and following seas for four speeds are studied for all configurations. Predicted responses to regular waves and to long crested irregular waves are presented. Comparisons are made among the configurations in which GM_L is varied and among those in which LCF is varied.

APPROACH

All configurations were generated by a numerical hull generation algorithm. Although the hydrostatic characteristics and the assumed geometry result in several equations, there are more unknowns than equations. The resulting nonlinear equations with specified constraints were solved iteratively to produce the hull forms. Eight configurations were generated, including a baseline, three GM_L variations, and four LCF variations. Among these configurations several characteristics such as LCB, waterplane area (A_w), and draft

*A complete list of references is given on Page 10

were nominally fixed. The resulting shapes (for one hull) are presented in Figures 1 and 2 and the corresponding characteristics are given in Table 1. A negative value of (LCB-LCF) indicates that the LCF is aft of the LCB. Note that these configurations have struts which extend aft of the lower hull so that the overall lengths are greater than the corresponding lower hull lengths.

All configurations had the same stabilizing fins. This was assumed to be acceptable since variations in hull characteristics were not dramatic. The forward and aft fins were located the same distance from the nose for all configurations. The origin of the coordinate system for the ship motions is assumed to be at the longitudinal center of gravity (LCG) and the LCG and LCB are assumed to be coincident. Since there is little variation in the LCB among the configurations, the fins generate approximately the same moments as well as forces for all configurations. Fin particulars are given in Table 2.

Motions in head and following waves for 0, 3, 10, and 15 knots were studied analytically. Transfer functions for heave, pitch, relative bow motion (RBM), absolute bow motion (ABM), and absolute stern motion (ASM) are presented for each condition as a function of wave length to ship length ratio (λ/L), where the values of L are given in Table 1. Motion at the bow is motion at the nose, and motion at the stern is motion at the trailing edge of the strut. Pitch is presented nondimensionally as pitch amplitude in radians per unit wave slope. The other motions are given as response amplitude per unit wave amplitude.

Responses to long crested irregular seas also are presented for the above conditions and motions. The Bretschneider spectral formulation which is a function of significant wave height and modal period is used to represent the seaway. Root mean squared (RMS) values of several motions are presented for several wave spectral modal periods at significiant wave heights of 3.05, 4.57, and 9.14 meters. Ochi's analysis of North Atlantic data [2] has been used to select the modal periods. For each significant wave height, the three modal periods studied correspond to the most probable and the upper and lower bounds of a 50% confidence band (i.e., the range of modal period, which will be encountered 50% of the time in the North Atlantic). Since in the Bretschneider formulation energy is proportional to the square of the significant wave height, responses to wave spectra with the same modal period but a different significant wave height can be calculated. The computed RMS value is multiplied by the

ratio of the desired significant wave height to the significant wave height used in the calculation to obtain the response to the desired significant wave height.

PRESENTATION AND DISCUSSION OF RESULTS

GM_L VARIATIONS

Four configurations, each having a different GM_L value were studied. GM_L ranged from 13.21 to 21.16 meters in increments of approximately 2.6 meters. Fo these configurations the LCB was approximately 30.4 meters and the LCF was 31.3 meters, aft of the nose. To facilitate comparisons, responses for all four configurations with GM_L variations are presented on the same graphs. Heave, pitch, RBM, ABM, and ASM transfer functions for configurations moving at 0, 3, 10, and 15 knots in head and following waves are presented in Figures 3 to 12.

Regular Waves

In head waves, the maximum heave amplitude per wave amplitude decreases as GM_L increases. For λ/L up to about 3, the heave transfer functions increase as GM_L increases. With further increase of λ/L, the trend is reversed. For λ/L of approximately 10 or greater, responses for the various configurations become identical. As GM_L increases, the corresponding pitch response decreases in magnitude. Generally, differences are notable for the entire λ/L domain. The pitch responses for the configuration with the smallest GM_L are notably larger than the responses for the other configurations. As GM_L increases, the peaks shift to smaller λ/L's. The shift in the pitch peak results directly from the increase in GM_L since the uncoupled, undamped pitch natural period, T_θ, is given by

$$T_\theta = 2\pi \left[\frac{I_{yy} + A_{55}}{m\ g\ GM_L}\right]^{1/2}$$

where I_{yy} is the mass moment of inertia about the y axis, A_{55} is the added mass in pitch due to pitching motions, m is the mass of the ship, and g is the acceleration due to gravity. At zero speed in deep water, λ_θ, the wavelength at the

natural period occurs, can be given by

$$\lambda_\theta = \frac{g\ T_\theta^{\ 2}}{2\pi}$$

With I_{yy} and A_{55} fixed, as GM_L increases T_θ and λ_θ will decrease. For the configurations with GM_L's of 13.21, 15.89, 18.49, and 21.16 meters, the corresponding T_θ's are 10.1, 9.2, 8.5, and 8.1 seconds, and the corresponding λ_θ /L's and .5, 2.1, 1.8, and 1.6. Reference to Figures 4 and 9 indicates that the pitch transfer functions peak at approximately these λ_θ/L values.

For all speeds this shift in pitch natural frequency is reflected in the RBM, ABM, and ASM transfer functions; however, for all speeds there is usually an increase in the maxima of these responses as GM_L increases. This is due to changes in the phasing of heave relative to pitch. For RBM and ABM there is also generally a narrowing in the band of wave lengths to which there is a large response as GM_L increases. This is particularly true at 0 and 3 knots. Conversely, for ASM there is a broadening in the response band as GM_L increases. Transfer functions for the configuration with the lowest GM_L are generally broader banded and separated from the others.

In following waves, heave is essentially insensitive to GM_L. However, the pitch transfer functions vary with GM_L at 0 and 3 knots. As in head waves, as GM_L increases the pitch transfer function peaks shift to lower λ/L, and responses decrease in magnitude. At 10 and 15 knots the motion is highly damped with the responses generally decreasing slightly as GM_L increases. As in head waves, pitch affects RBM, ABM, and ASM. At 0 and 3 knots as GM_L increases, the maximum responses shift to smaller λ/L's. As in head waves, the transfer functions for the configuration with the lowest GM_L are often distinct from the others.

Irregular Seas

RMS values for heave, pitch, RBM, and ABM are given as a function of spectral modal period, T_o, in Figures 13 to 22. In head seas the effect of GM_L on the RMS values varies with speed and type of motion. At zero speed, RMS values generally decrease as GM_L increases except that ASM is lowest for the

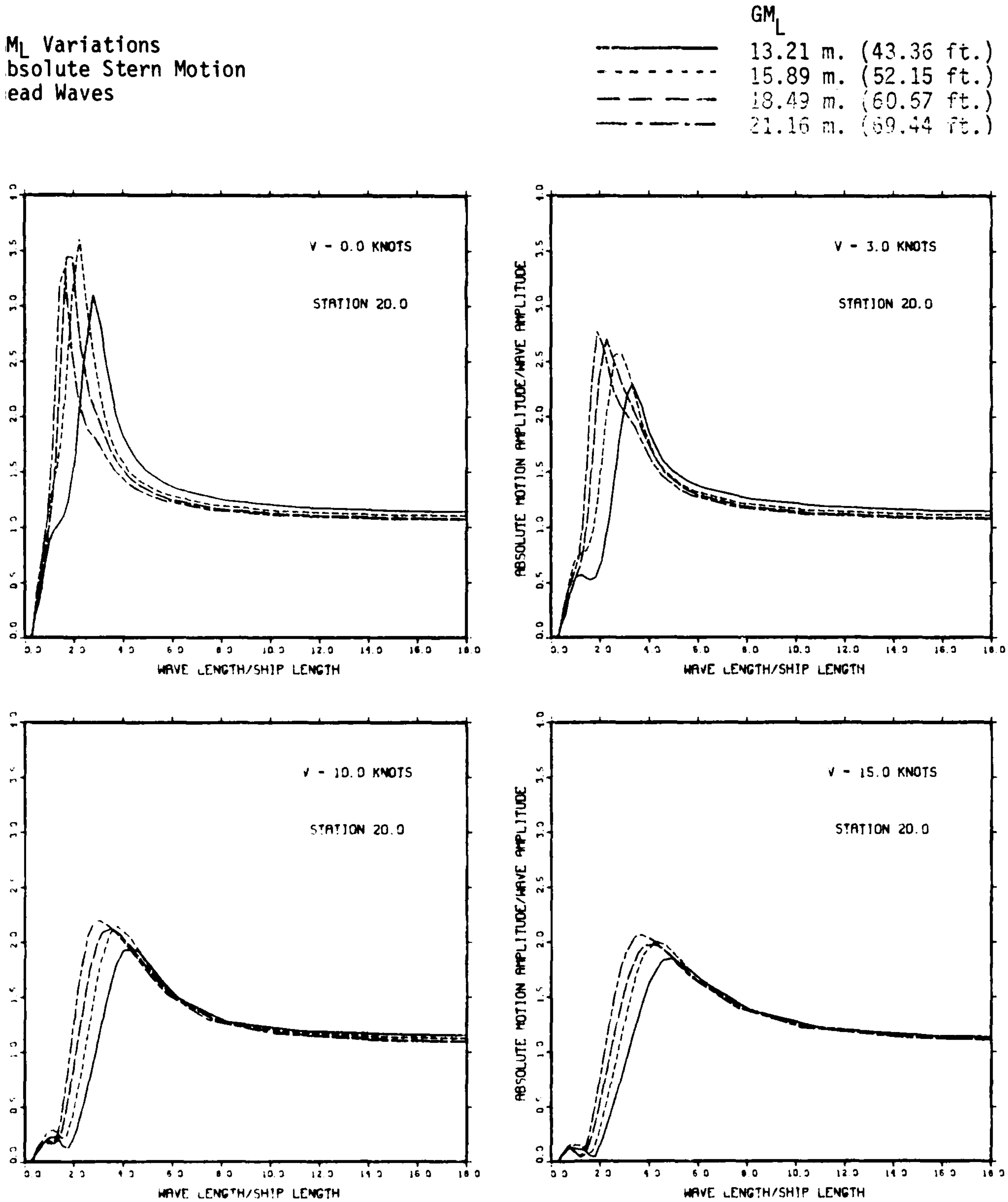

Figure 7 - Absolute Stern Motion Transfer Functions in Regular Head Waves for Configurations in the GM_L Series

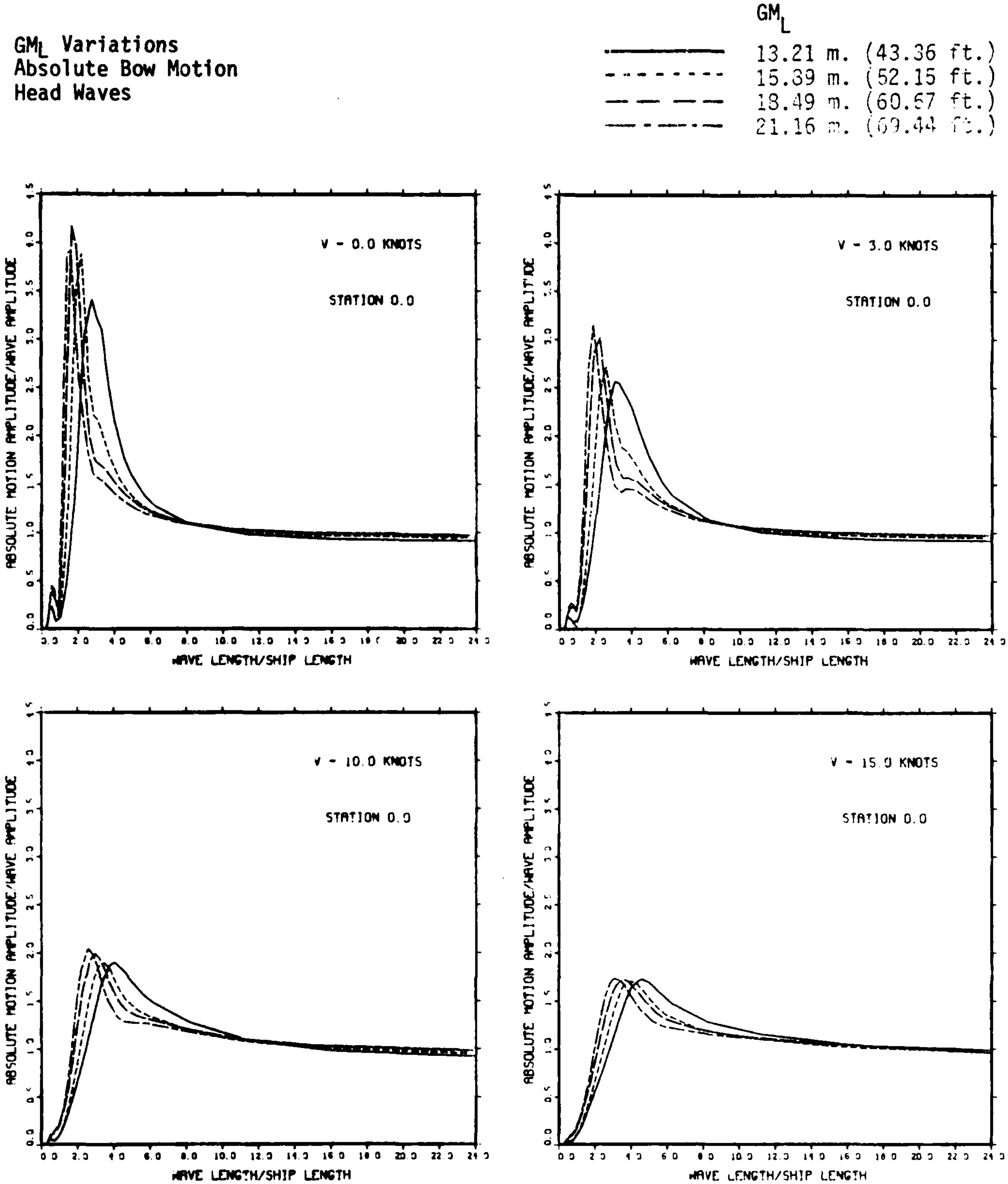

Figure 6 - Absolute Bow Motion Transfer Functions in Regular Head Waves for Configurations in the GM$_L$ Series

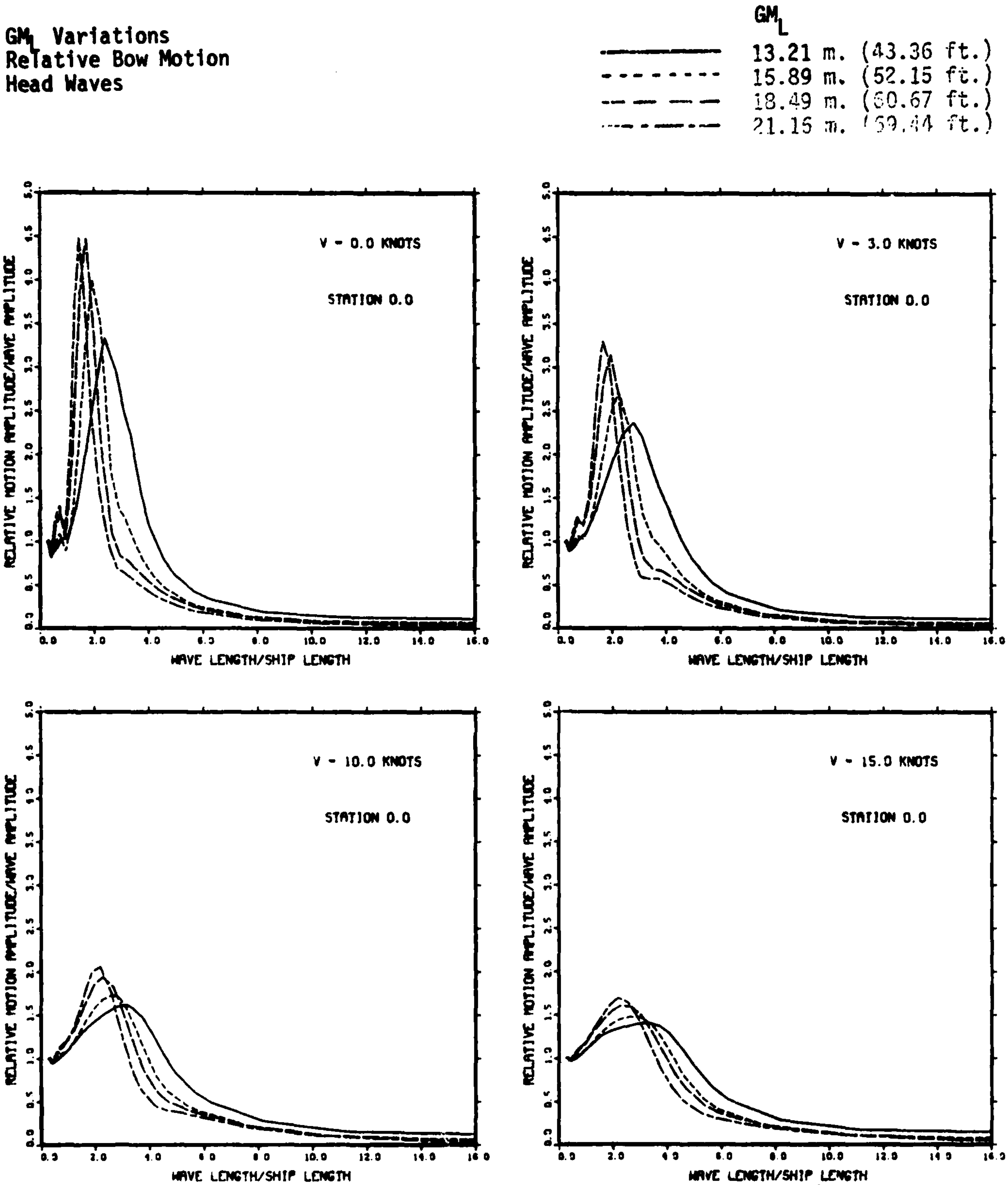

Figure 5 - Relative Bow Motion Transfer Functions in Regular Head Waves for Configurations in the GM$_L$ Series

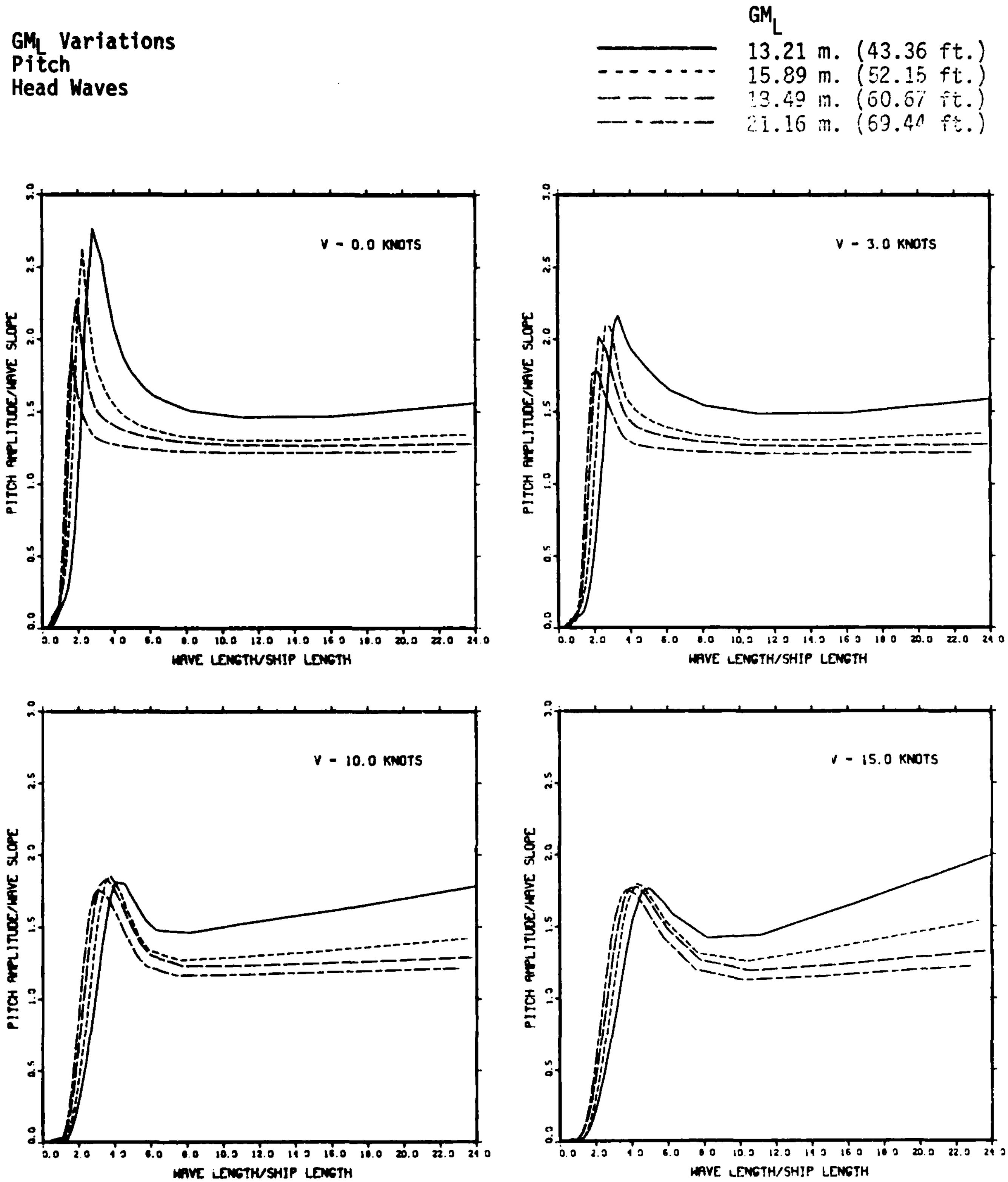

Figure 4 - Pitch Transfer Functions in Regular Head Waves for Configurations in the GM$_L$ Series

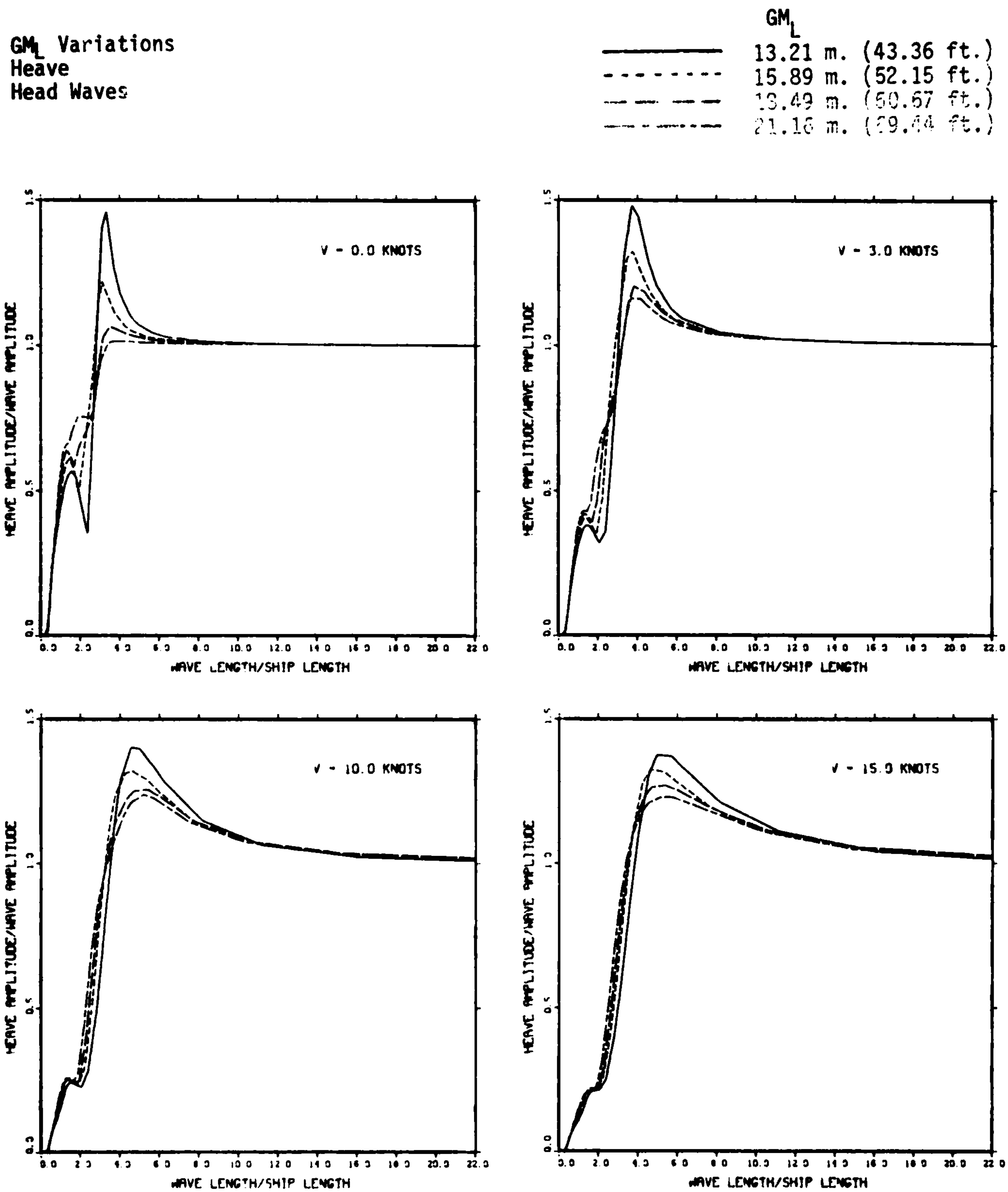

Figure 3 - Heave Transfer Functions in Regular Head Waves for Configurations in the GM$_L$ Series

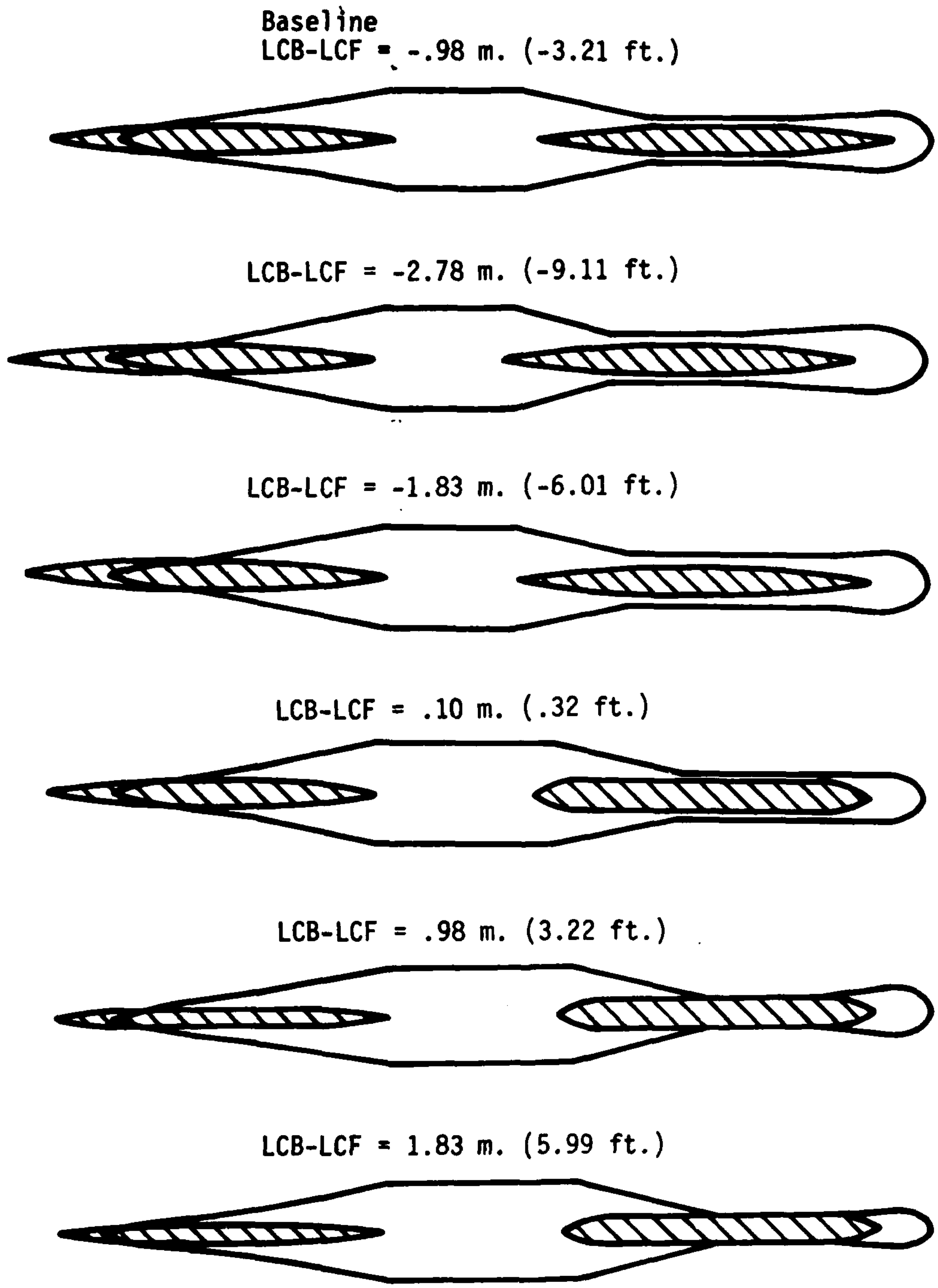

Figure 2 - Sketches of One Hull of Configurations in the LCF Series

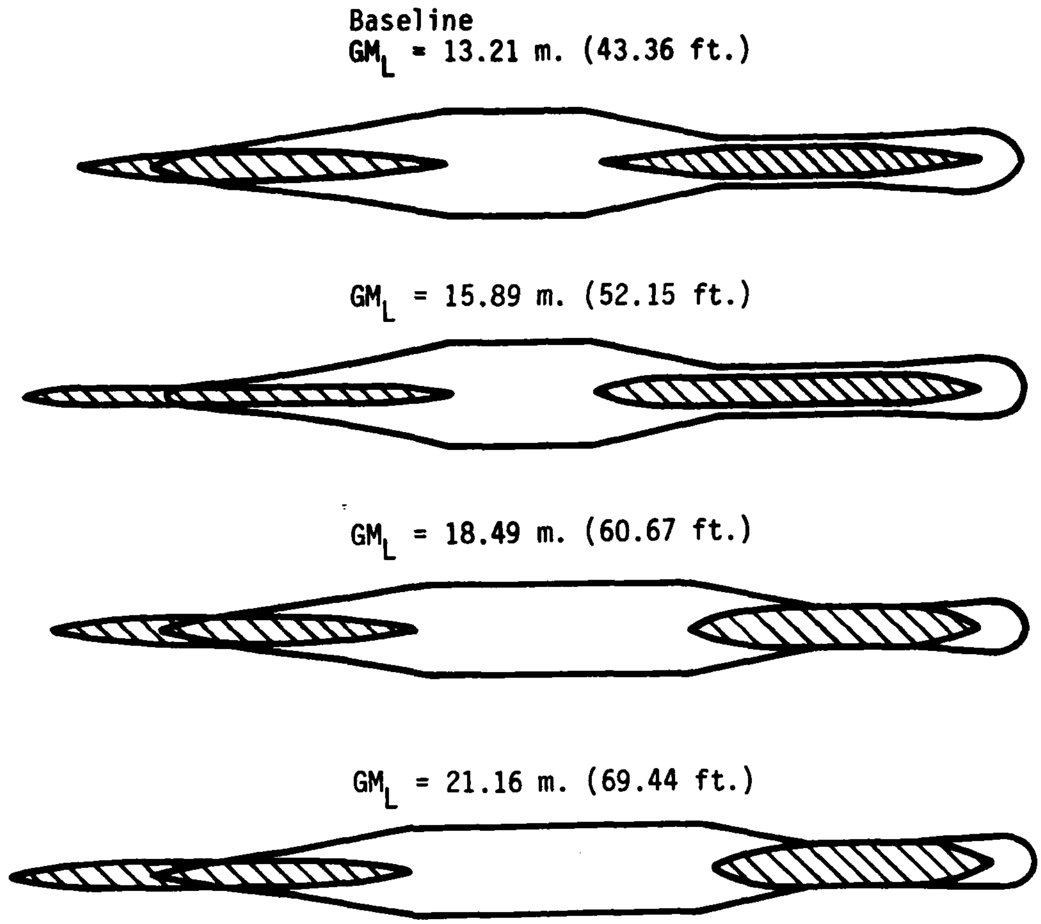

Figure 1 - Sketches of One Hull of Configurations in the GM_L Series

TABLE 2 - CHARACTERISTICS OF STABLIZING FINS

	Forward	Aft
Chord, m	2.08	2.55
Span, m	4.16	5.10
Maximum Thickness, m	0.34	0.42
Distance from Nose to Quarter-Chord, m	11.42	52.87

Table 1 - CHARACTERISTICS OF CONFIGURATIONS

	Baseline	GM_L Variations			LCF Variations				
Length Overall (L), m	61.32	65.58	64.58	66.87	63.73	62.67	61.26	61.71	60.92
Length Lower Hull, m	55.18	57.55	56.68	57.32	57.23	56.40	56.35	56.78	57.27
GM_L*, m	13.21	15.89	18.49	21.16	13.08	13.09	13.26	13.25	13.06
LCF*, m	31.29	31.28	31.26	31.23	33.26	32.28	30.28	29.28	28.40
LCB*, m	30.21	30.40	30.44	30.47	30.48	30.45	30.38	30.26	30.26
(LCB-LCF), m	-1.08	-0.88	-0.82	-0.76	-2.78	-1.83	0.10	0.98	1.83
(LCB-LCF)/L	-0.017	-0.013	-0.013	-0.011	-0.044	-0.029	0.002	0.016	0.030
Transverse Metacentric Height, m	2.08	2.05	1.84	1.80	2.01	2.02	2.03	2.04	2.00
Waterplane Area, m^2	151.4	151.5	151.5	152.0	151.6	151.5	151.6	151.4	150.8
Displacement, tonne	2539.	2548.	2552.	2558.	2560.	2555.	2549.	2552.	1551.

*GM_L = Longitudinal Metacentric Height

LCF = Longitudinal Center of Flotation Aft of Nose

LCB = Longitudinal Center of Buoyancy Aft of Nose

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1. McCreight, K.K. and Ralph Stahl, "Regular Wave Responses and Stability Characteristics of a Systematic Series of Unappended SWATH Designs," DTNSRDC Ship Performance Department SPD-0886-01, February 1980.
2. Ochi, Michel K., "Wave Statistics for the Design of Ships and Ocean Structures," Transactions of the Society of Naval Architects and Marine Engineers, 1978.

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15.89 meters does not significantly reduce motions.

4. As the LCF is moved from aft to forward of the LCB, RMS values for head seas responses generally increase. An exception to this is heave at 0 and 3 knots. The effect of LCF is not significant at 0 and 3 knots, with RMS values for the configuration with the forward-most LCF location being as much as twice those for the configuration with the aft-most location.

5. In following seas at 0 and 3 knots, bow motion and other responses increase as the LCF is moved forward of the LCB. However, at 15 knots RBM, ABM, and ASM RBM decrease as the LCF is moved forward of the LCB; this is also true for RBM at 10 knots.

6. Among configurations studies, the results show that in head seas variation in the LCF location results in a broader range of response values than does variation in GM_L. Locating the LCF forward of the LCB consistently reduces responses whereas the effect of GM_L varies. However, in following seas, an increase in GM_L generally is more effective than a change in LCF in reducing responses except for RBM where response changes are comparable.

waves, the heave transfer functions tend to increase as the LCF is moved forward; whereas, at lower wave lengths in following seas, the heave transfer functions decrease with the same change in LCF. In head waves at 0 and 3 knots and in following waves, pitch usually increases as the LCF is moved from aft to forward of the LCB. Pitch dominates the relative and absolute motions. The reason changes in LCF produce these changes in responses is complex and requires further investigation.

Irregular Seas

The RMS values of responses associated with for the LCF variations are presented in Figures 33 to 42. In head seas the RMS values increase for the most part as the LCF is moved from aft to forward of the LCB for all conditions and responses except heave at 0 and 3 knots which decrease. At 10 and 15 knots, heave and absolute stern motion show little sensitivity to LCF location. Sensitivity to LCF location is strong for pitch, RBM, and ABM, with RMS values of the responses to LCF most forward being as much as twice those with LCF aft. At 0 and 3 knots the responses for the three configurations with the LCF forward of the LCB are often close in magnitude. At 10 and 15 knots the changes in responses are essentially proportional to changes in the LCF location.

In following seas the effect of LCF location on the RMS values is not consistent. Sensitivity to LCF location is less pronounced than in head seas but is significant, expecially for motion at the bow. Generally, as the LCF is moved forward of the LCB, responses increase at 0 and 3 knots; whereas, at 10 knots results are mixed, and at 15 knots responses decrease.

CONCLUSIONS

1. Increasing GM_L decreases the pitch natural period, resulting in a shift in the pitch, RBM, ABM and ASM transfer functions.
2. In head seas for ship speeds of 3, 10, and 15 knots for all wave spectral modal periods, heave RMS and ABM RMS generally decrease as GM_L increases, while pitch RMS and ASM RMS generally increase as GM_L increases.
3. In following seas, an increase from 15.89 meters to 18.49 meters and from 18.49 meters to 21.16 meters in GM_L generally results in a decrease in responses. However, the results indicate that increasing the GM_L from 13.21 meters to

13.21 meter-GM_L configuration. This reduction is as large as 20%. At 3, 10, and 15 knots, heave, RBM and ABM usually decrease and pitch and ASM increase as GM_L increases. The reduction in RMS due to increasing GM_L is between 0% and 10%. The effect tends to diminish with increasing speed for heave, RBM, and ABM.

In following seas, GM_L has minimal effect on heave RMS. GM_L has a significant effect on the magnitude of RMS values for all the other responses at all the speeds studied. The change in RMS due to variations in GM_L are as high as 40%. The RMS values generally decrease as GM_L increases for all speeds at all modal periods. However, for several responses the RMS values for the configuration with the lowest GM_L of 13.21 meters are equal to or less than those for the configuration with the GM_L of 15.89 meters.

LCF VARIATION

Six configurations, each having a different LCF value were investigated. The LCB is approximately 30.4 meters from the nose for all configurations, with LCF varying from 28.40 meters to 33.26 meters from the nose. As shown in Table 1, this corresponds to an (LCB-LCF)/L variation from -0.044 to -0.028 in increments of approximately 0.015 as shown in Table 1. It was not possible to generate a configuration with the LCF farther forward without changing either A_w or GM_L. For these configurations A_w and GM_L were approximately 151.0 m^2 and 13.2 m, respectively.

Regular Waves

Heave, pitch, RBM, ABM, and ASM transfer functions for configurations moving at 0, 3, 10, and 15 knots. In head and following waves are presented in Figures 23 to 32. The heave transfer functions cross at a point so that on one side of that point at each wavelength, heave increases for configurations as the LCF is moved forward of the LCB. On the other side of that point heave decreases. In head waves, on the left of that pivot point at each wavelength, heave decreases with an increase in the LCF. This behavior is not evident at 0 and 3 knots. Heave is relatively insensitive to change in LCF at 10 and 15 knots. The crossover point is near the pitch natural period. The trends are opposite in following waves. That is, at the shorter wave lengths in head

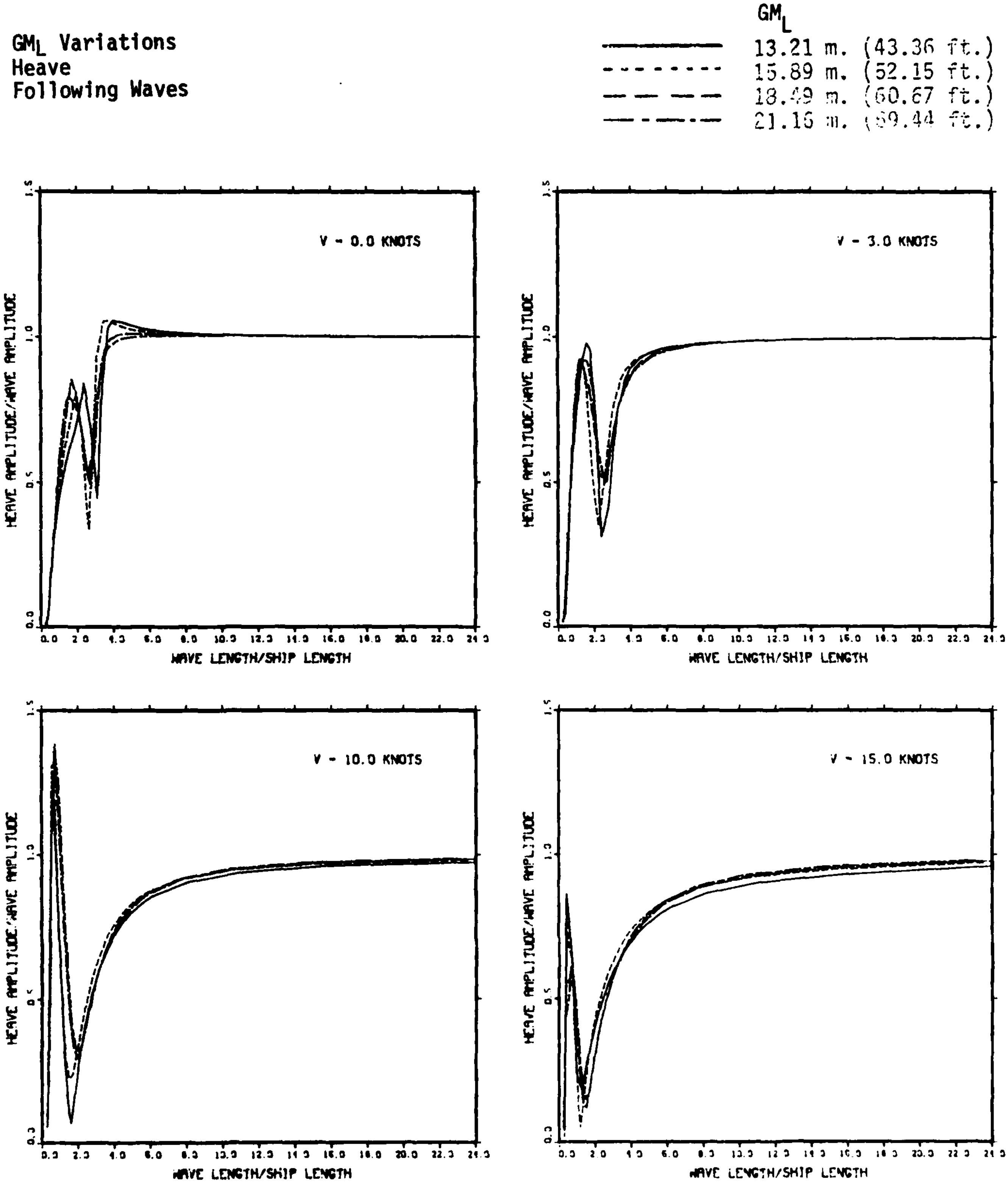

Figure 8 - Heave Transfer Functions in Regular Following Waves for Configurations in the GM$_L$ Series

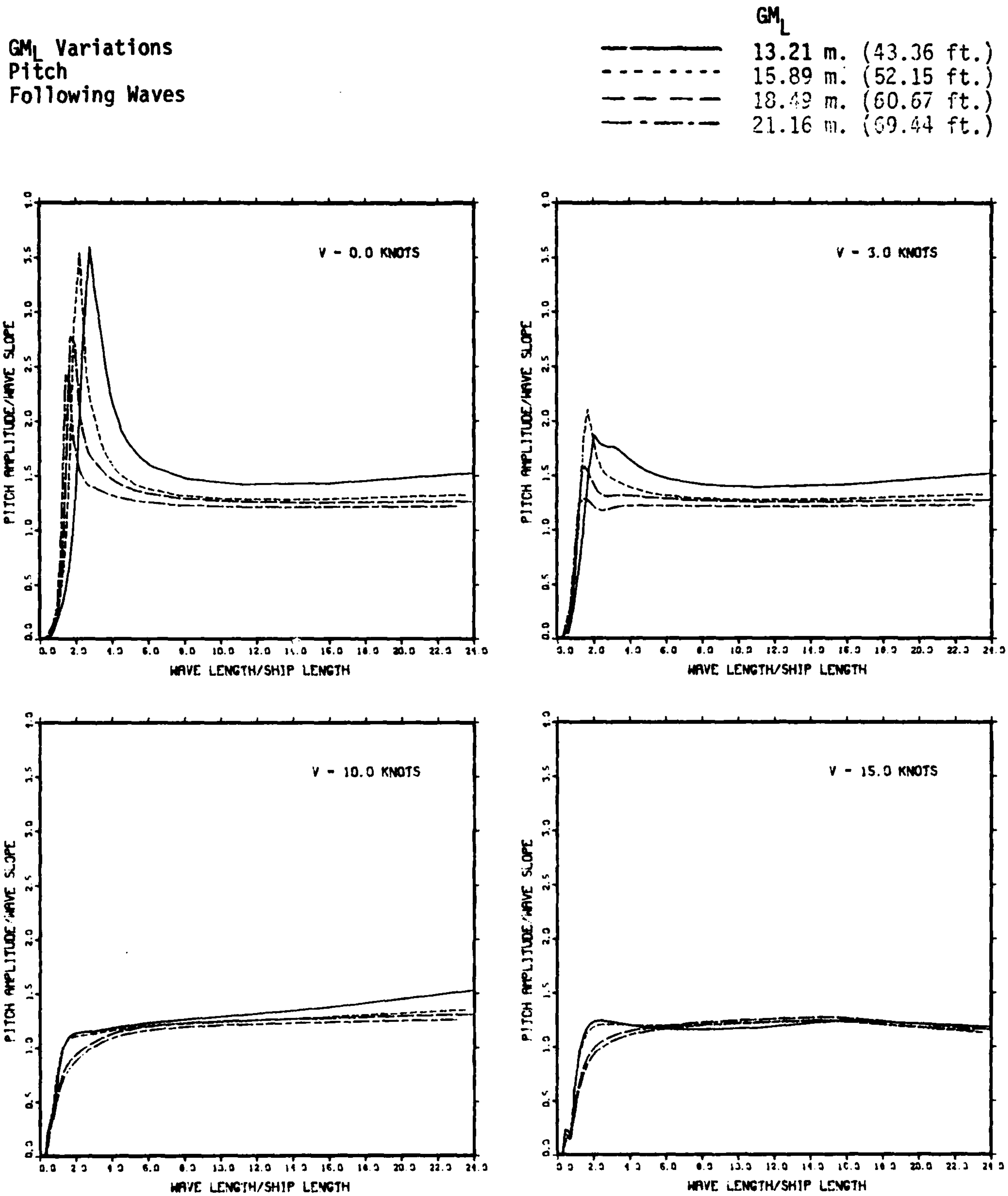

Figure 9 - Pitch Transfer Functions in Regular Following Waves for Configurations in the GM_L Series

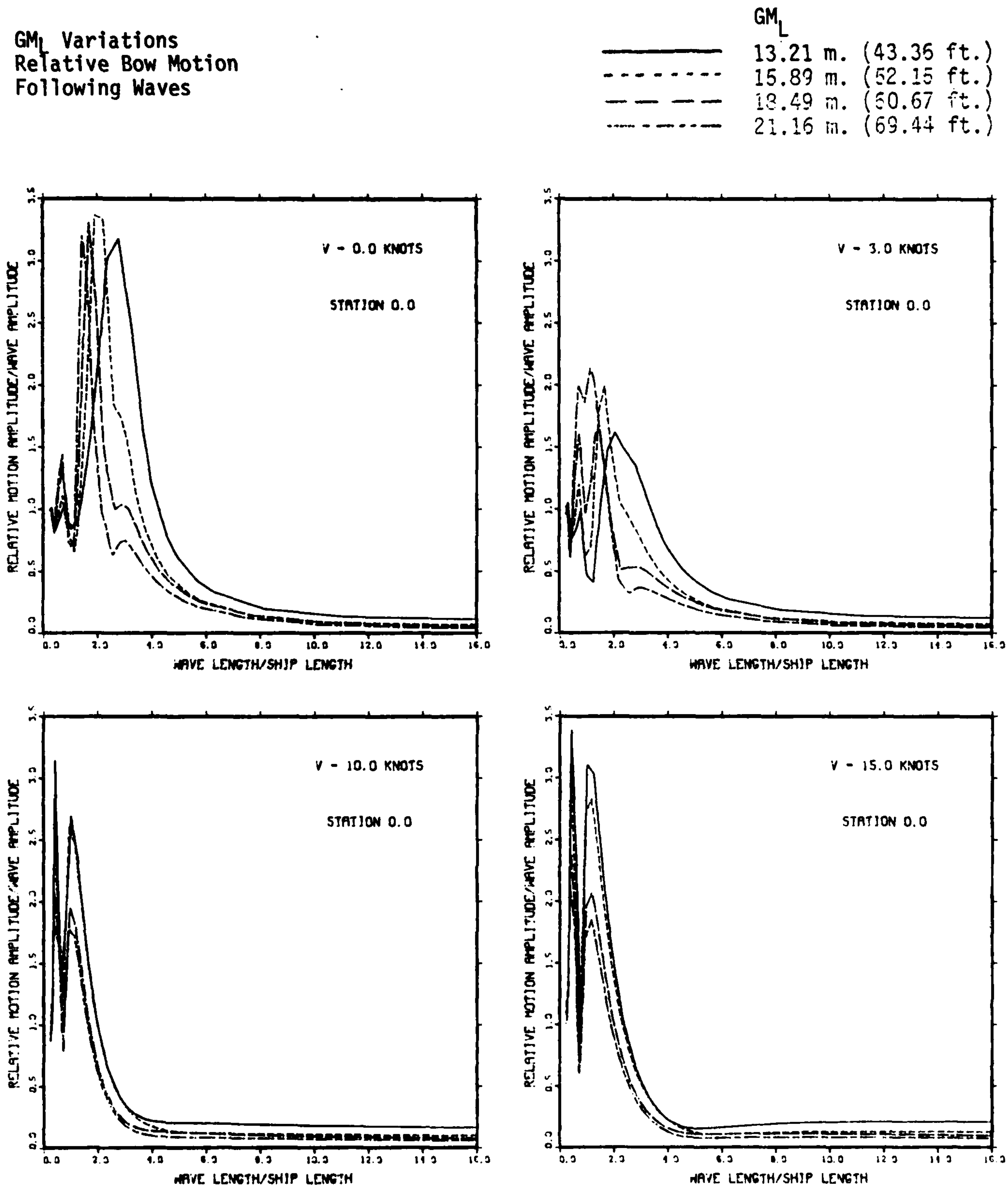

Figure 10 - Relative Bow Motion Transfer Functions in Regular Following Waves for Configurations in the GM$_L$ Series

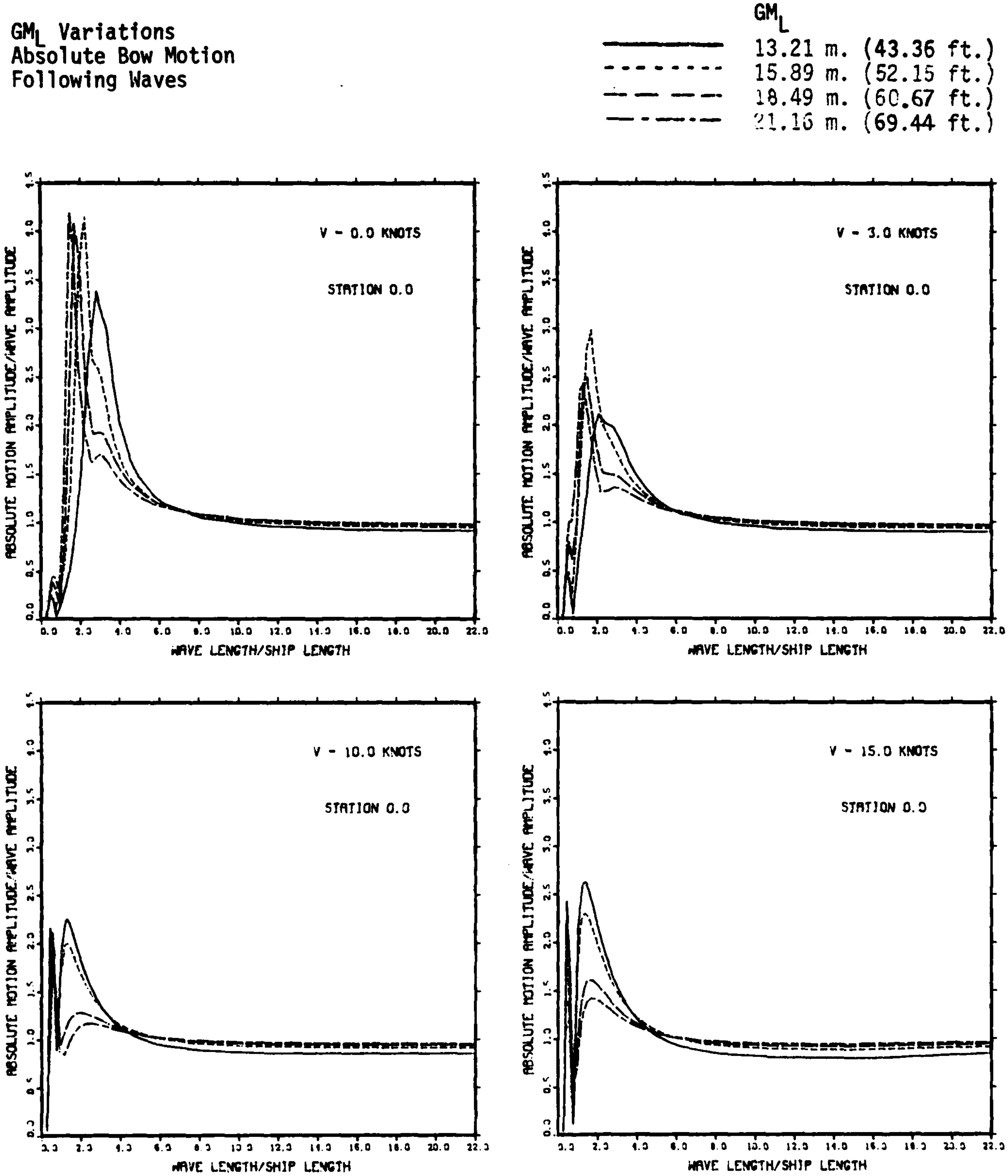

Figure 11 - Absolute Bow Motion Transfer Functions in Regular Following Waves for Configurations in the GM$_L$ Series

GM$_L$ Variations
Absolute Stern Motion
Following Waves

	GM$_L$
————	13.21 m. (43.36 ft.)
- - - - - - - -	15.89 m. (52.15 ft.)
— — — —	18.49 m. (60.67 ft.)
---- - ---- -	21.16 m. (69.44 ft.)

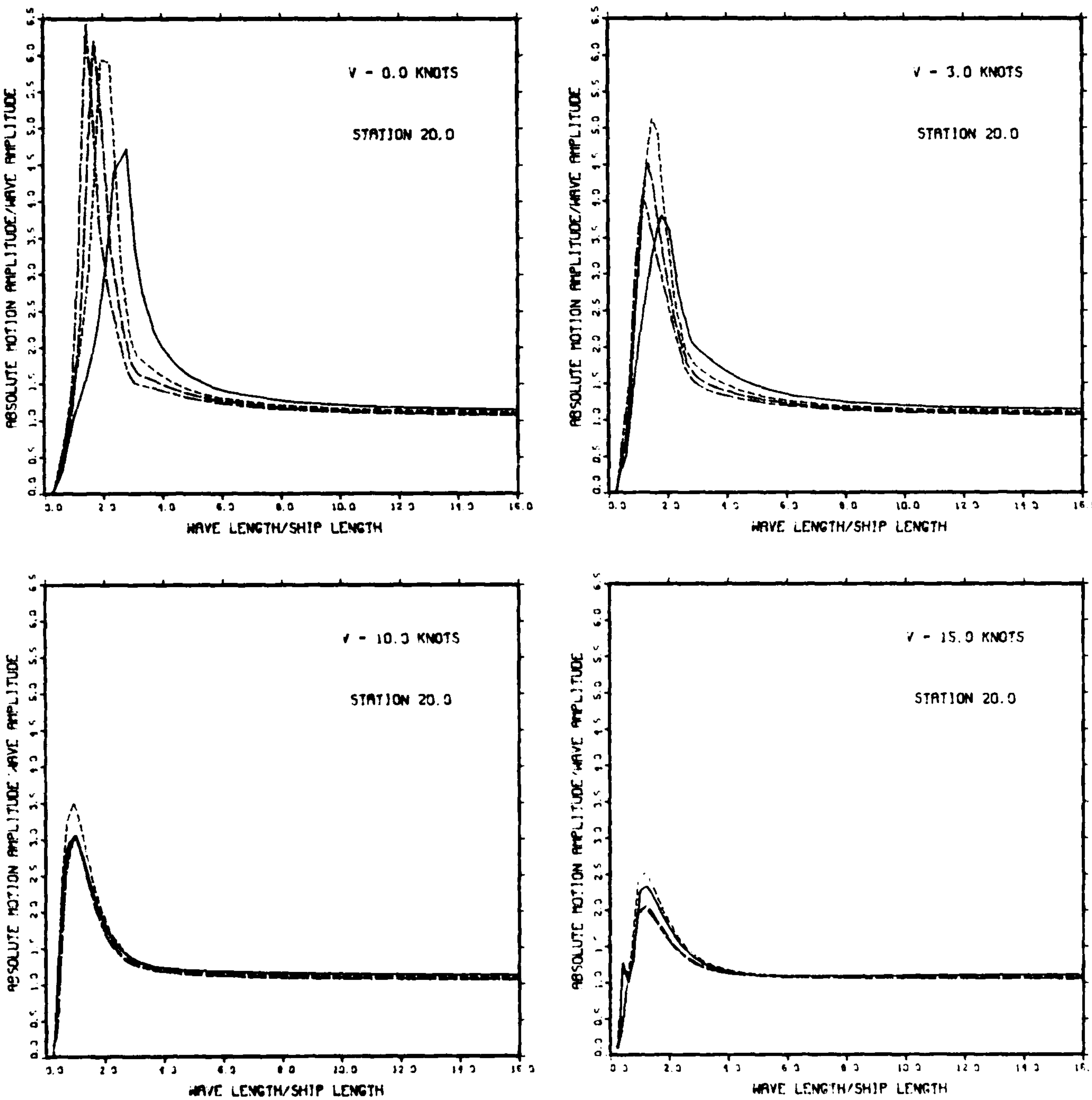

Figure 12 - Absolute Stern Motion Transfer Functions in Regular Following Waves for Configurations in the GM$_L$ Series

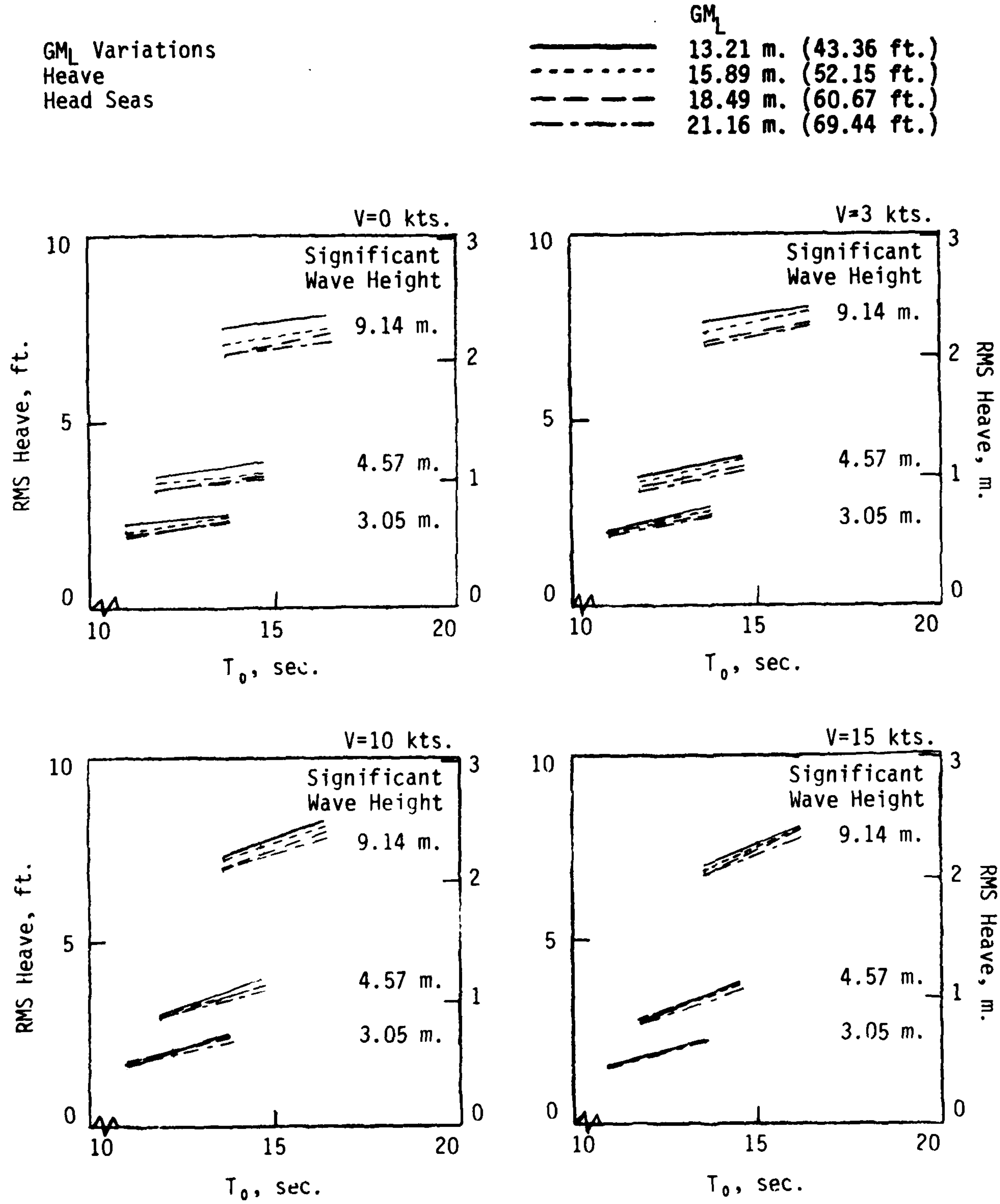

Figure 13 - Heave RMS Responses in Irregular Head Seas for Configurations in the GM$_L$ Series

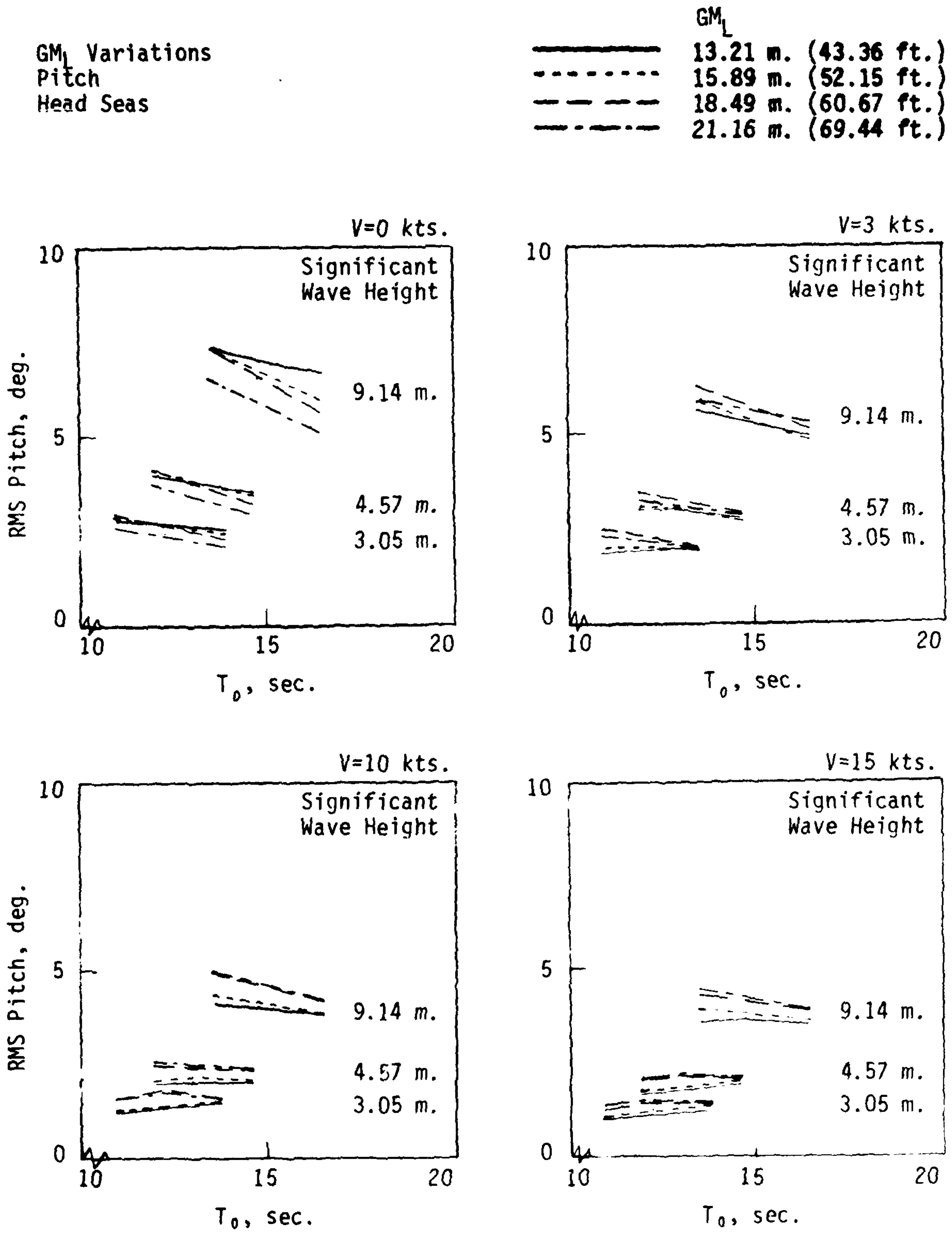

Figure 14 - Pitch RMS Responses in Irregular Head Seas for Configurations in the GM$_L$ Series

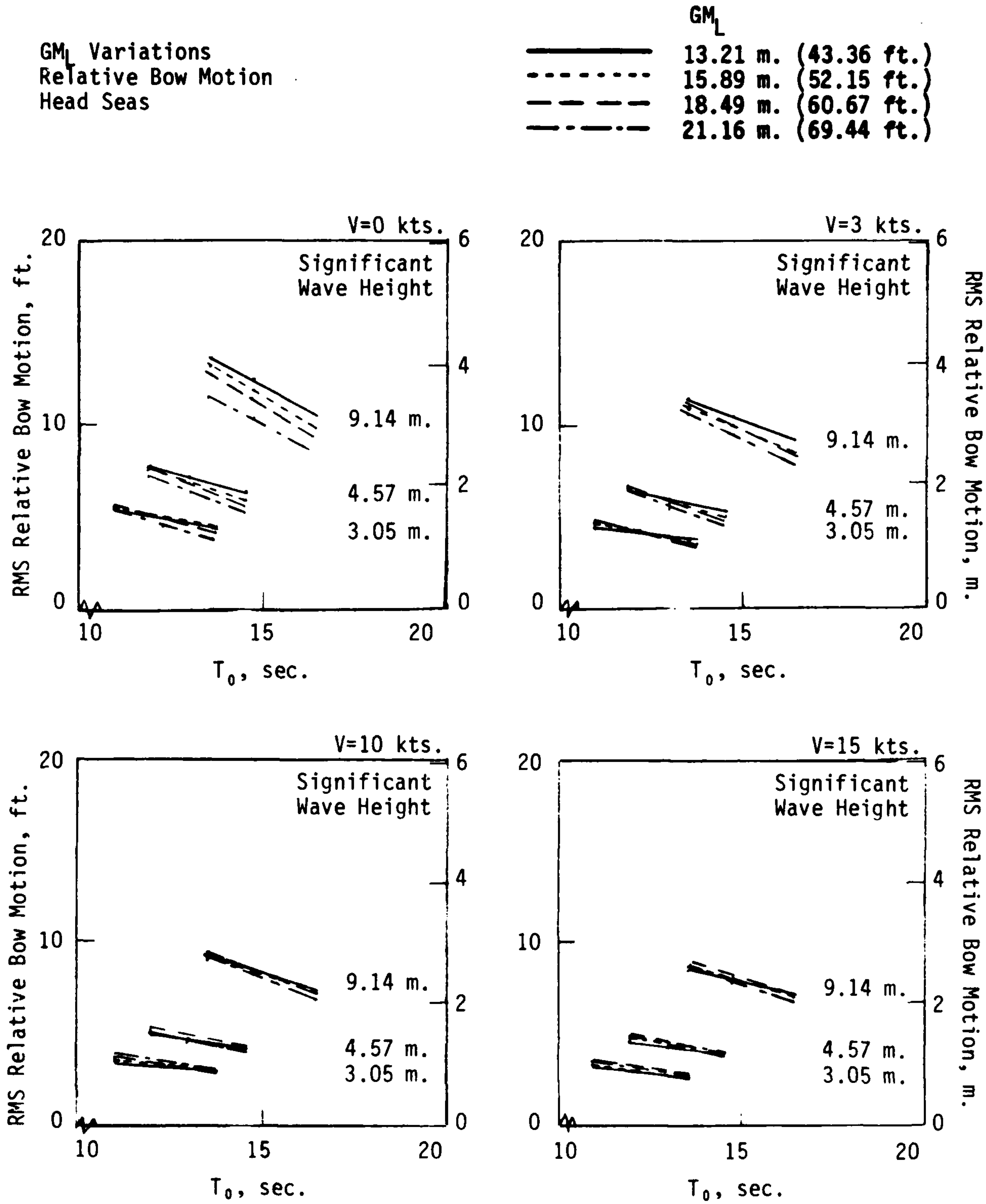

Figure 15 - Relative Bow Motion RMS Responses in Irregular Head Seas for Configurations in the GM_L Series

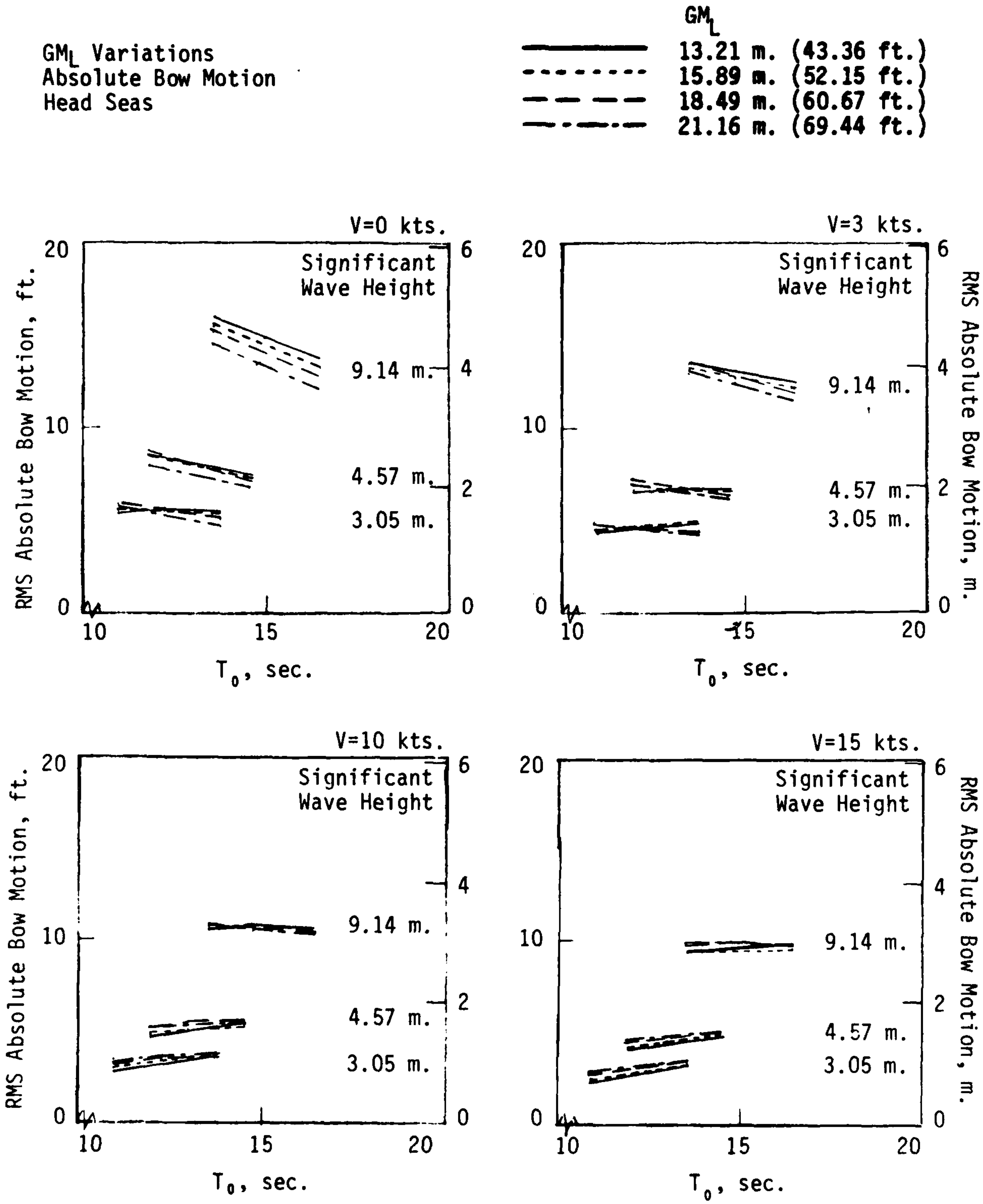

Figure 16 - Absolute Bow Motion RMS Responses in Irregular Head Seas for Configurations in the GM$_L$ Series

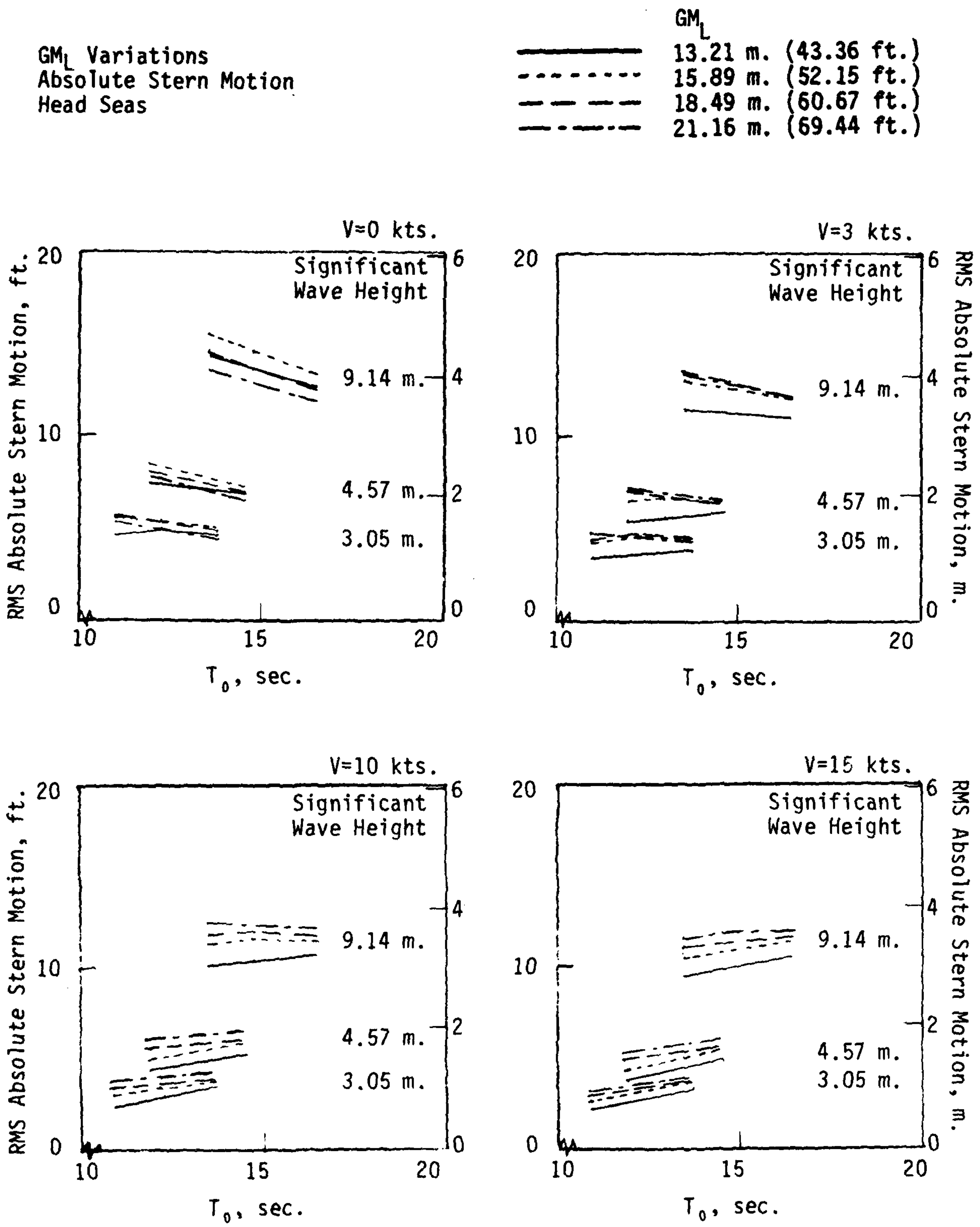

Figure 17 - Absolute Stern Motion RMS Responses in Irregular Head Seas for Configurations in the GM_L Series

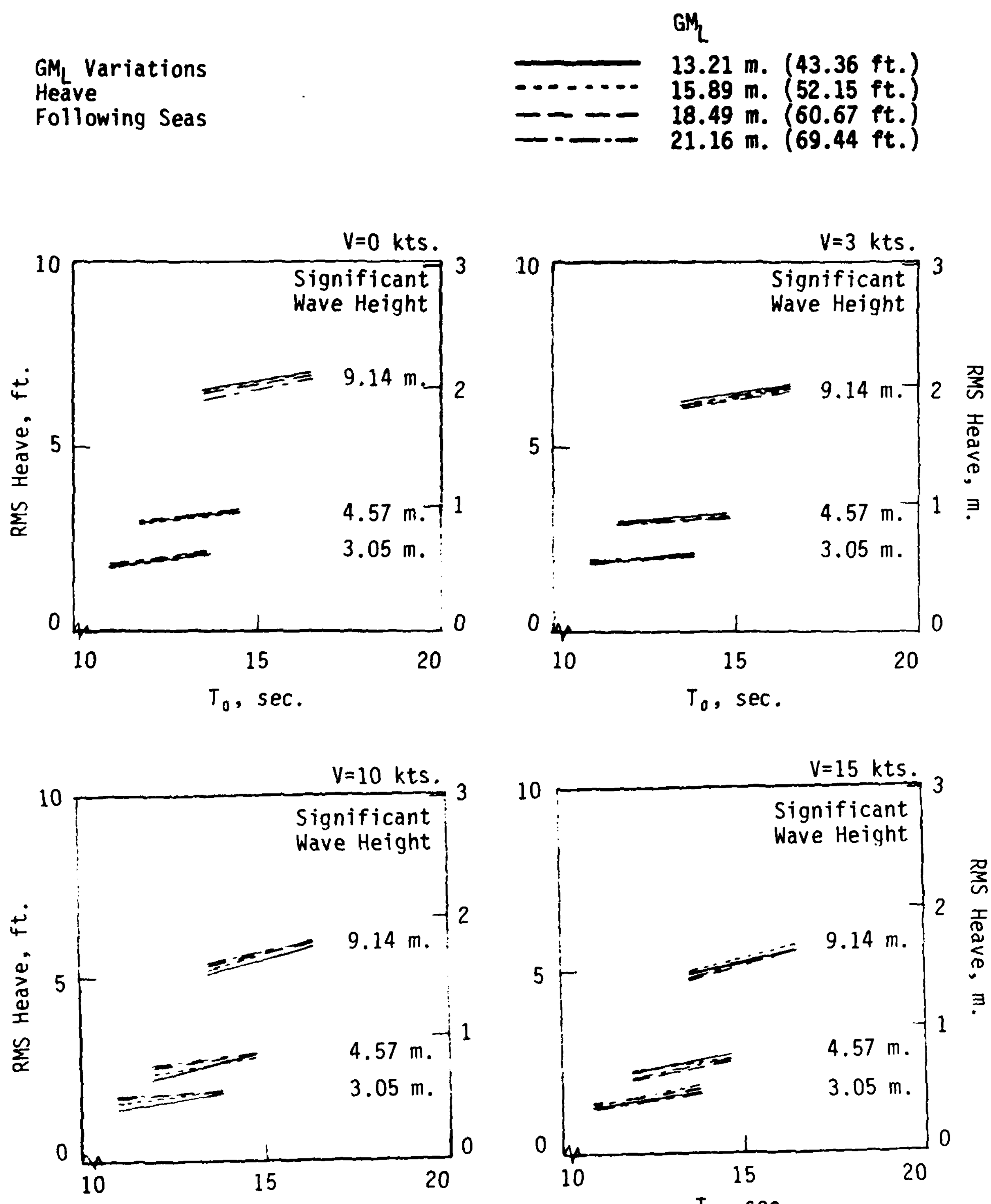

Figure 18 - Heave RMS Responses in Irregular Following Seas for Configurations in the GM_L Series

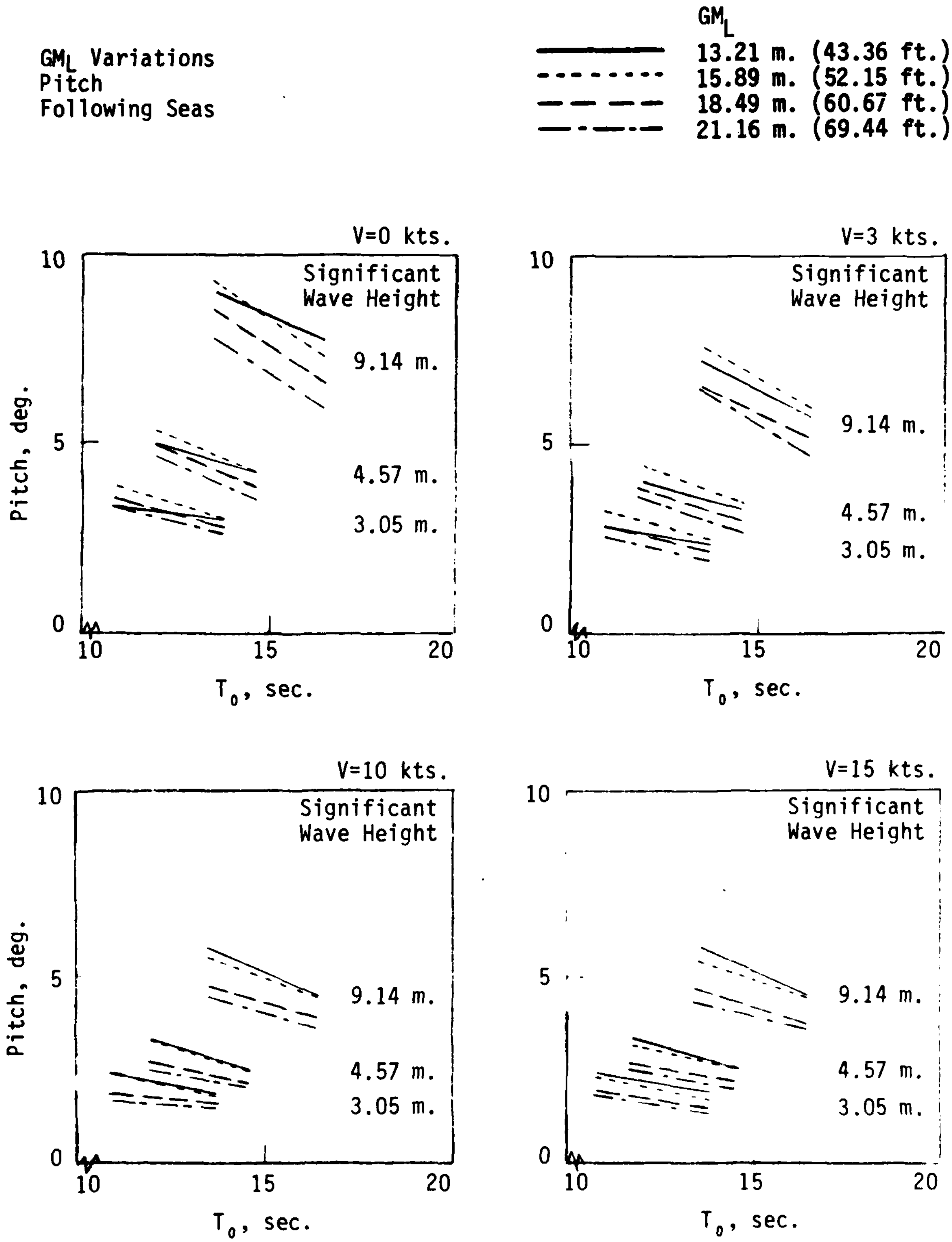

Figure 19 - Pitch RMS Responses in Irregular Following Seas for Configurations in the GM$_L$ Series

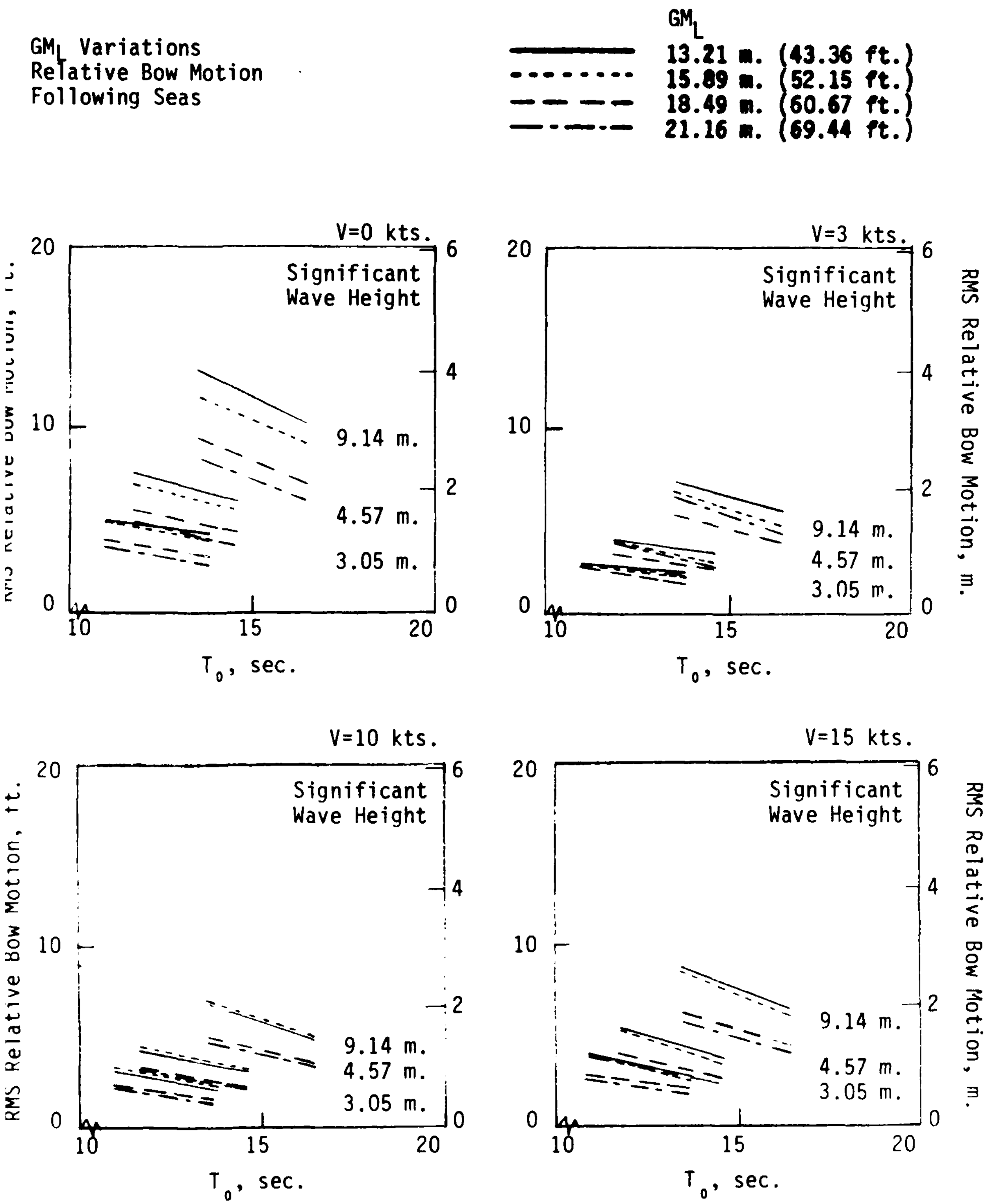

Figure 20 - Relative Bow Motion RMS Responses in Irregular Following Seas for Configurations in the GM_L Series

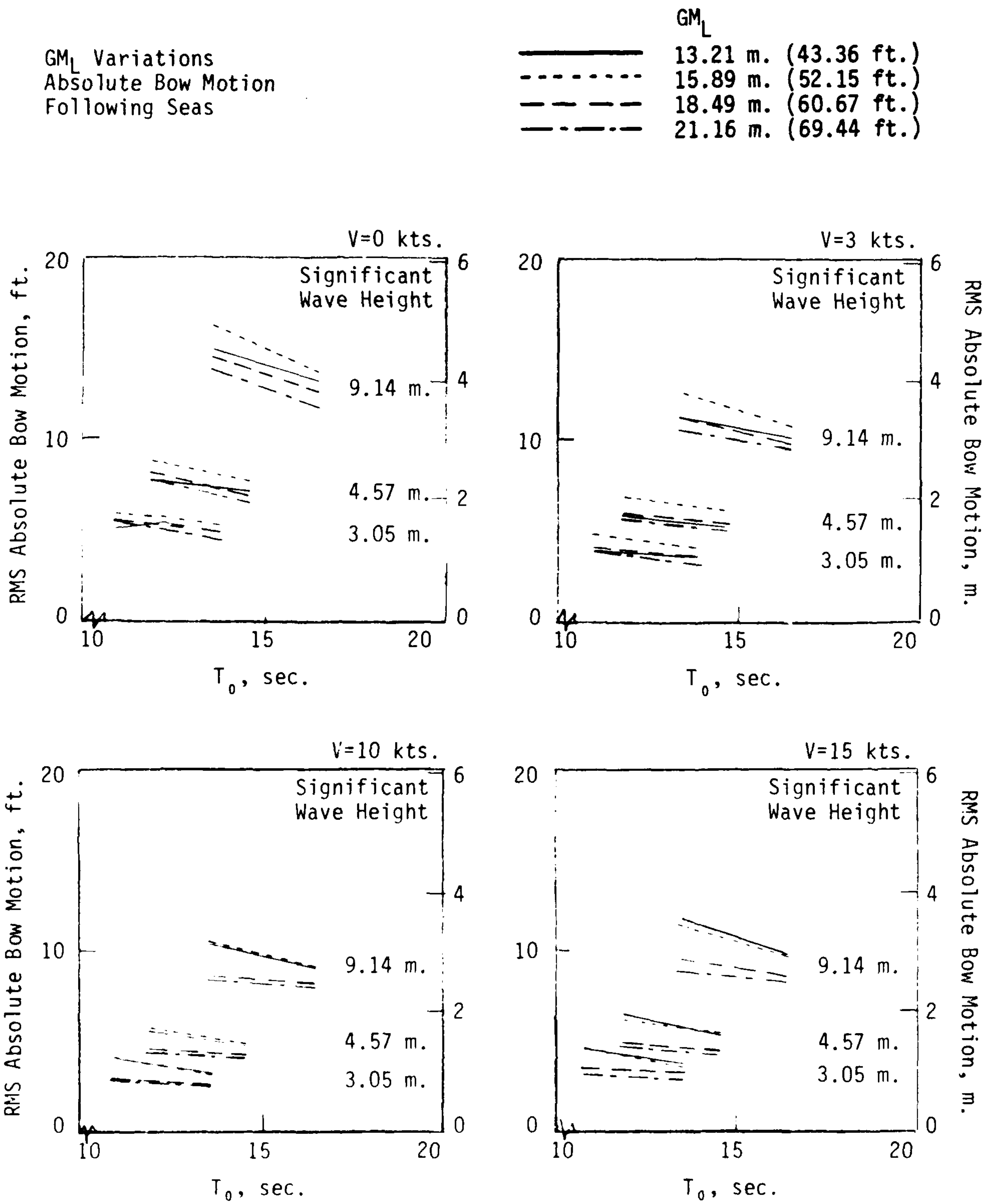

Figure 21 - Absolute Bow Motion RMS Responses in Irregular Following Seas for Configurations in the GM_L Series

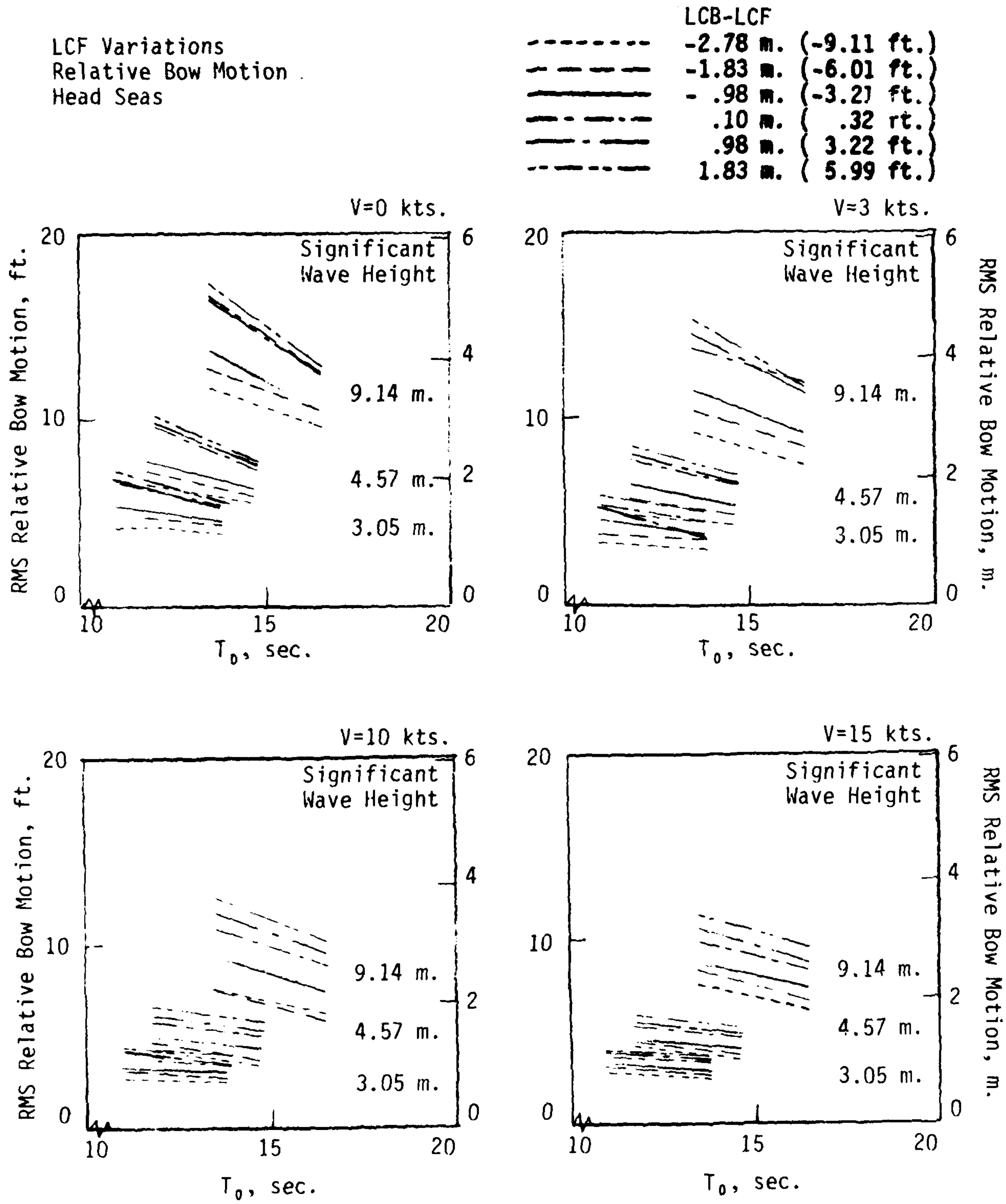

Figure 35 - Relative Bow Motion RMS Responses in Irregular Head Seas for Configurations in the LCF Series

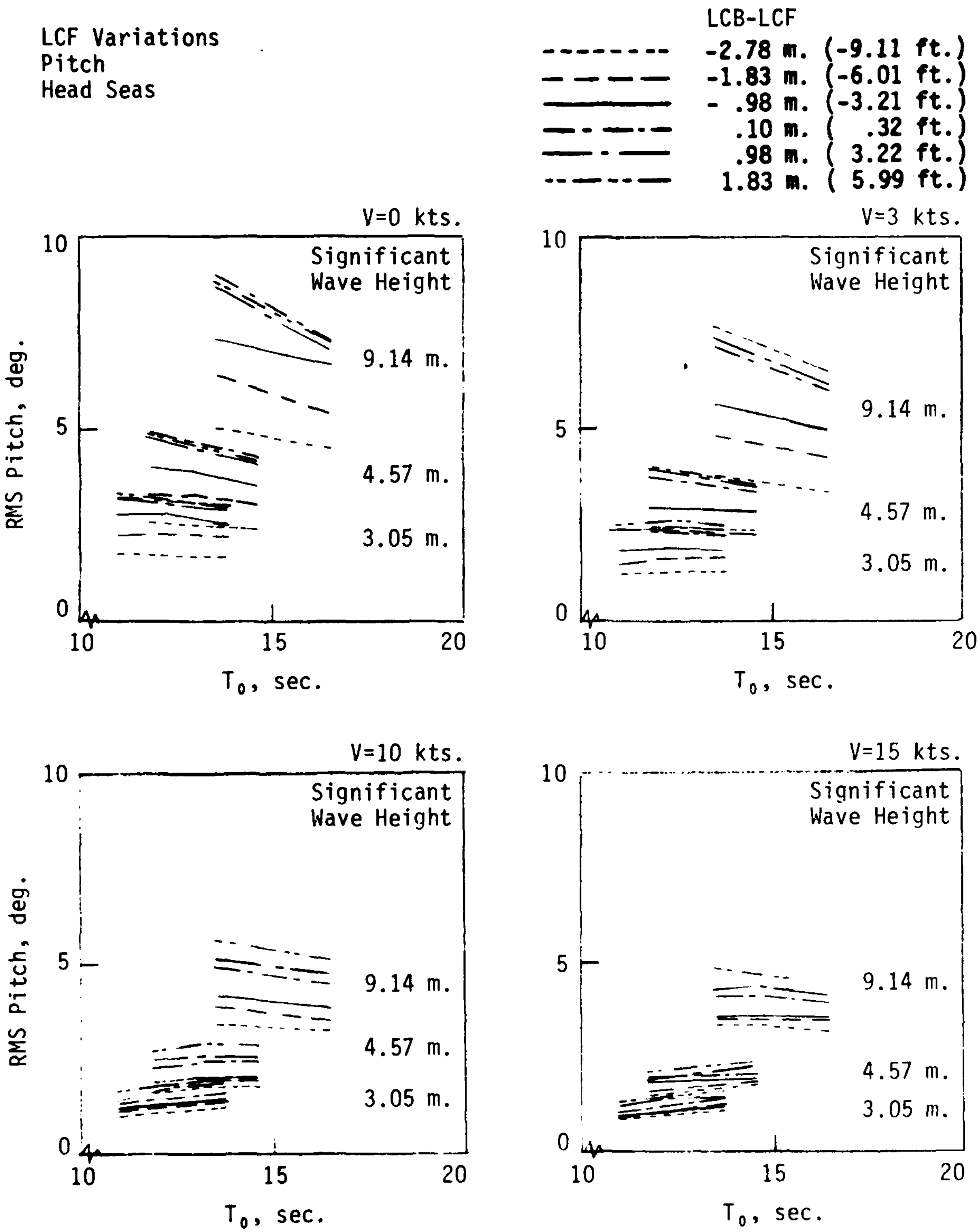

Figure 34 - Pitch RMS Responses in Irregular Head Seas for Configurations in the LCF Series

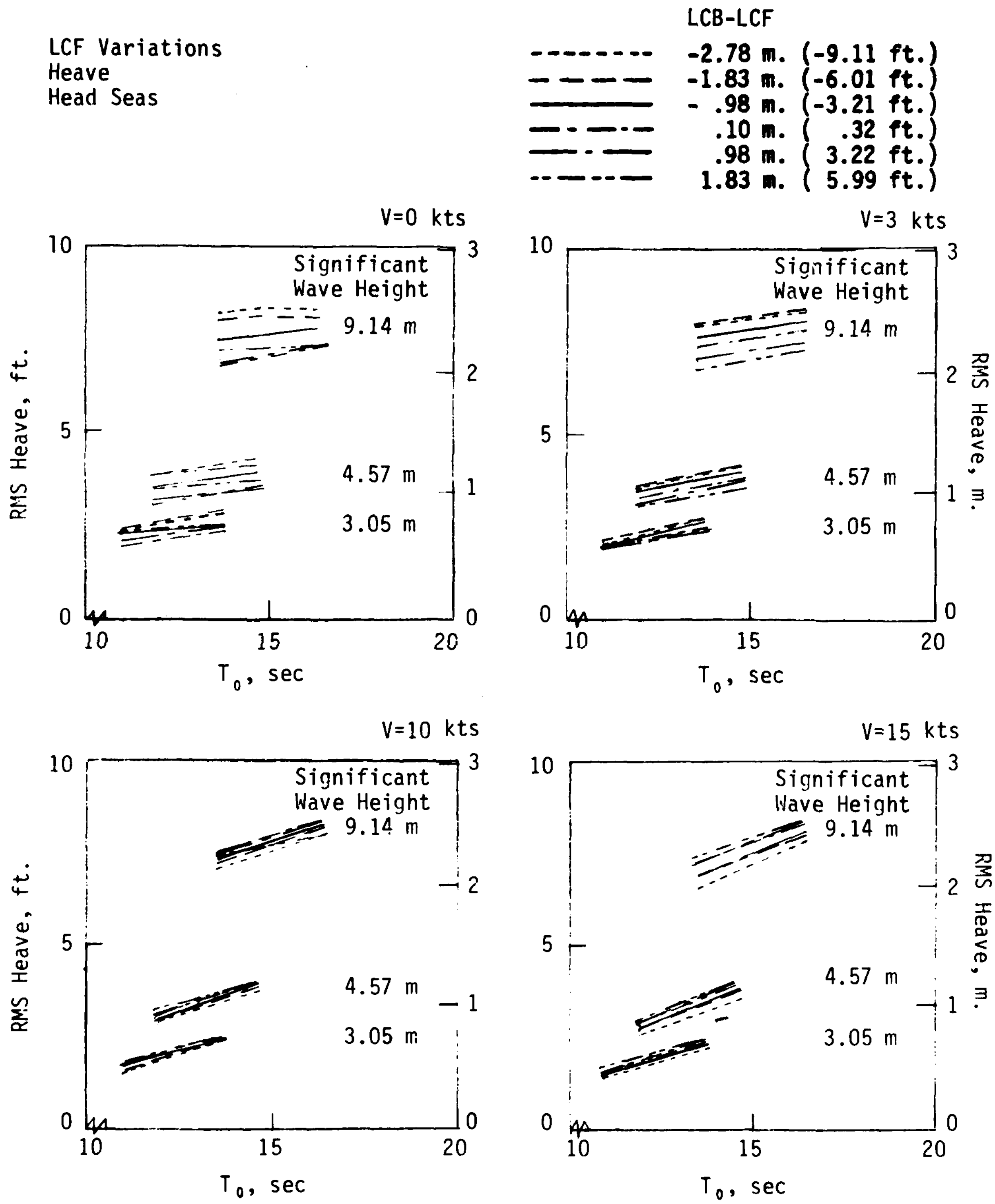

Figure 33 - Heave RMS Responses in Irregular Head Seas for Configurations in the LCF Series

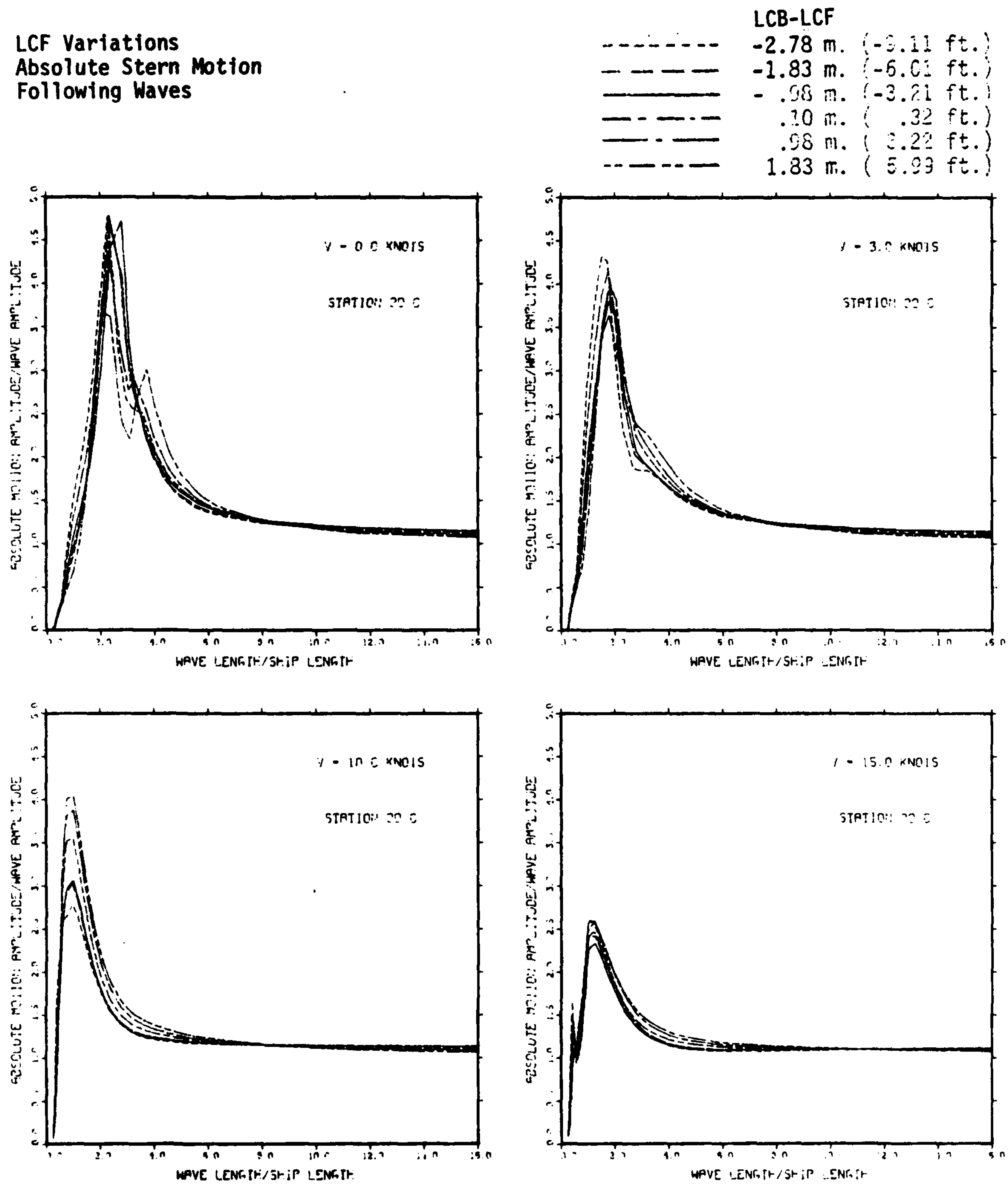

Figure 32 - Absolute Stern Motion Transfer Functions in Regular Following Waves for Configurations in the LCF Series

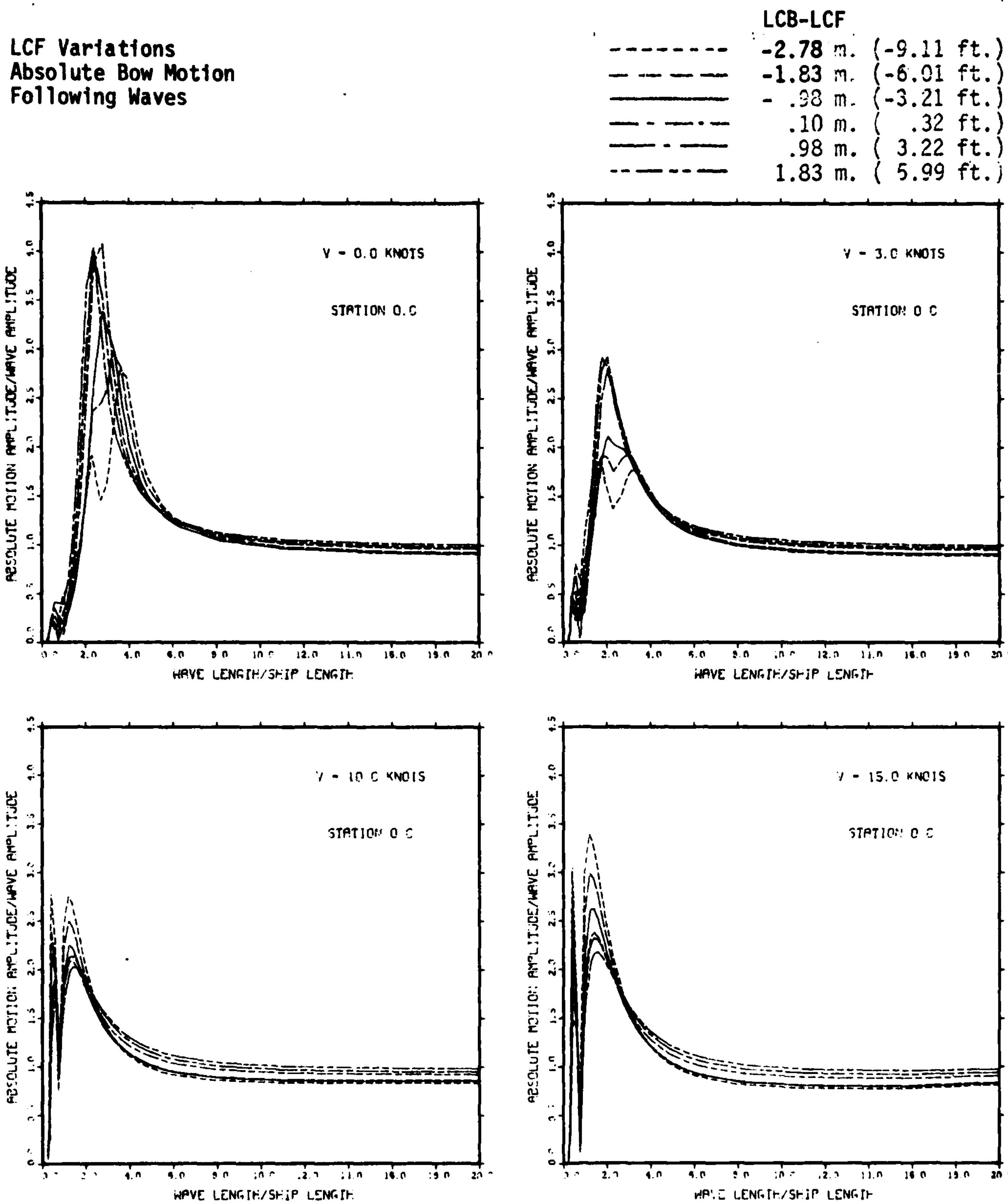

Figure 31 - Absolute Bow Motion Transfer Functions in Regular Following Waves for Configurations in the LCF Series

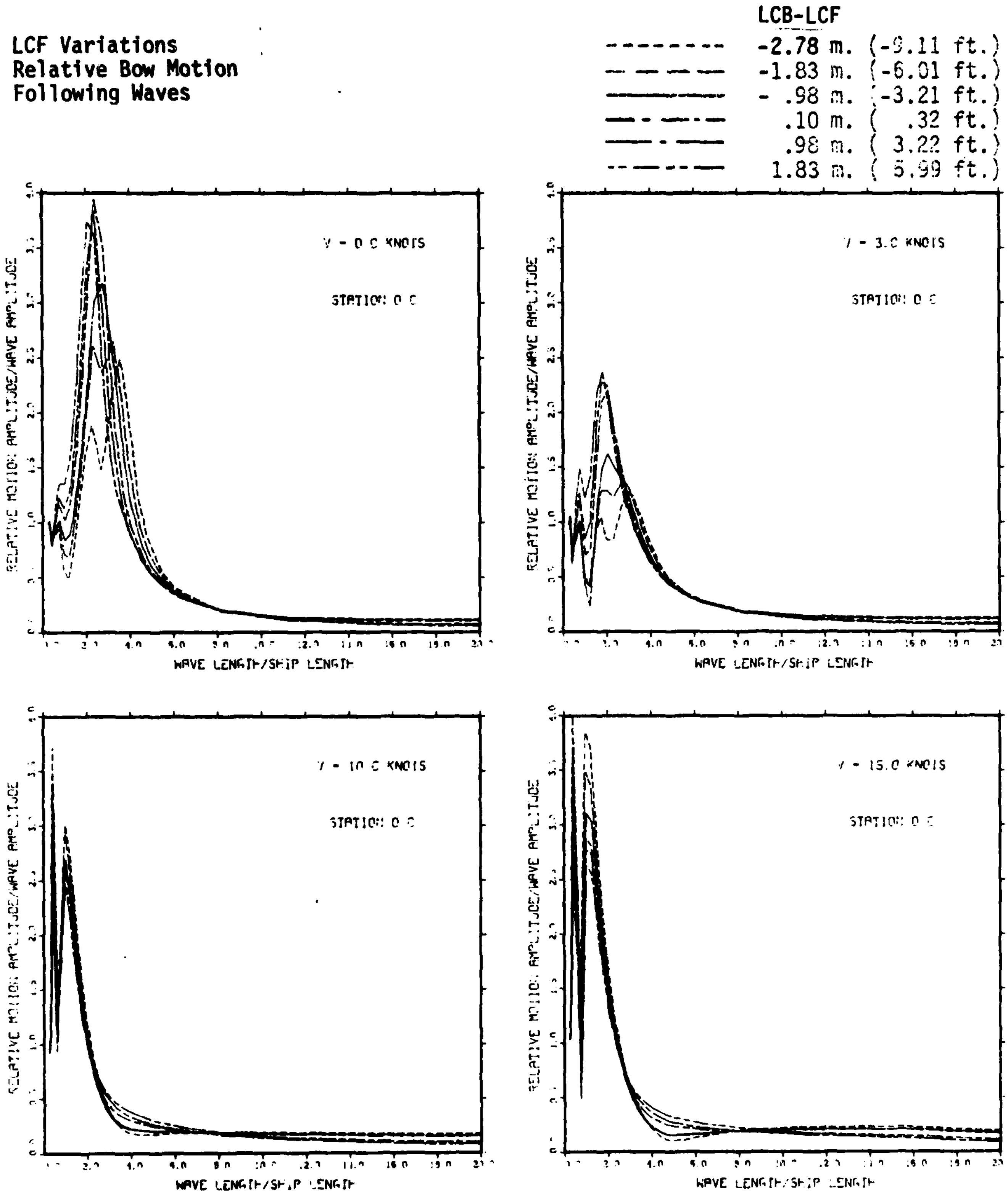

Figure 30 - Relative Bow Motion Transfer Functions in Regular Following Waves for Configurations in the LCF Series

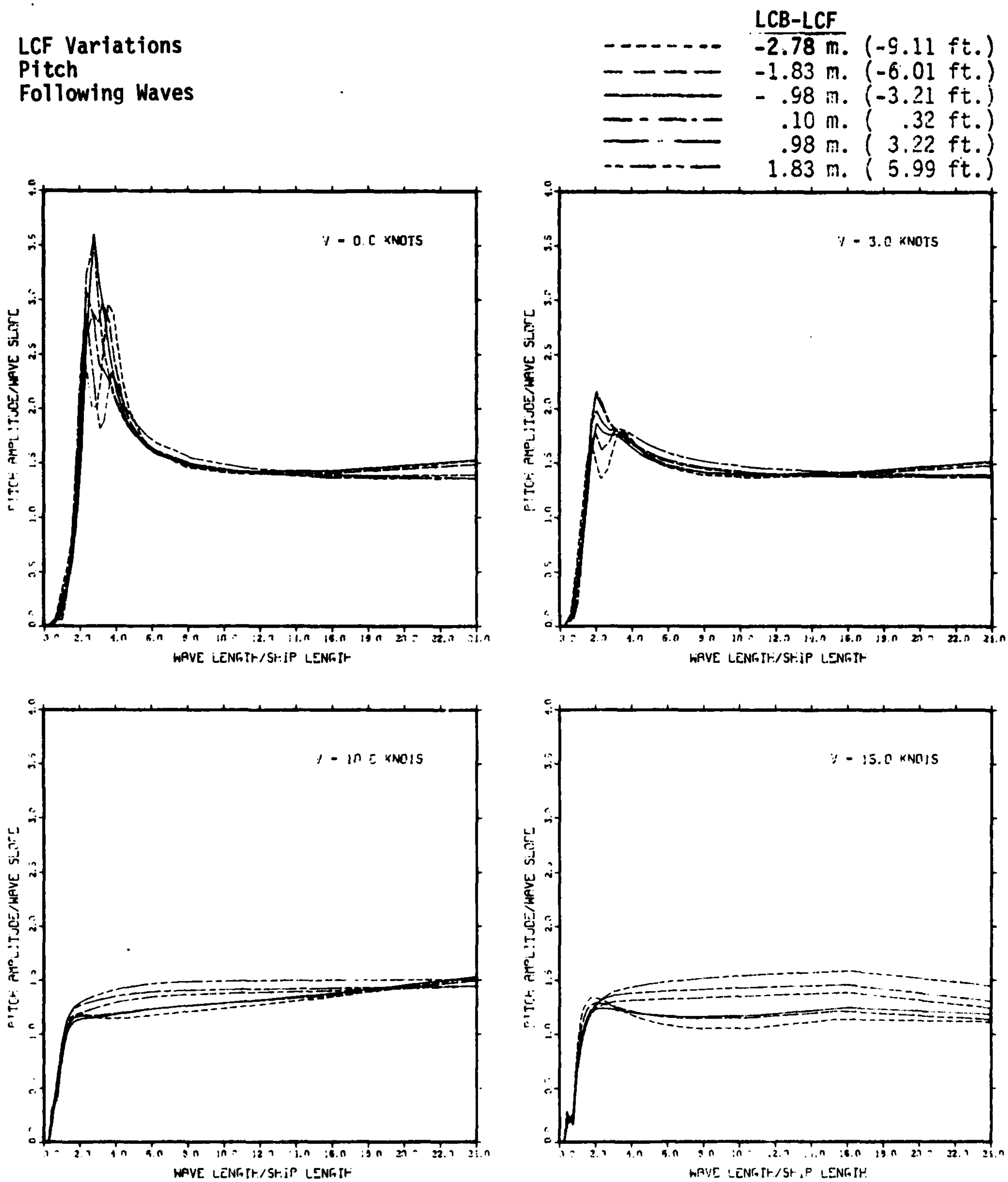

Figure 29 - Pitch Transfer Functions in Regular Following Waves for Configurations in the LCF Series

LCF Variations
Heave
Following Waves

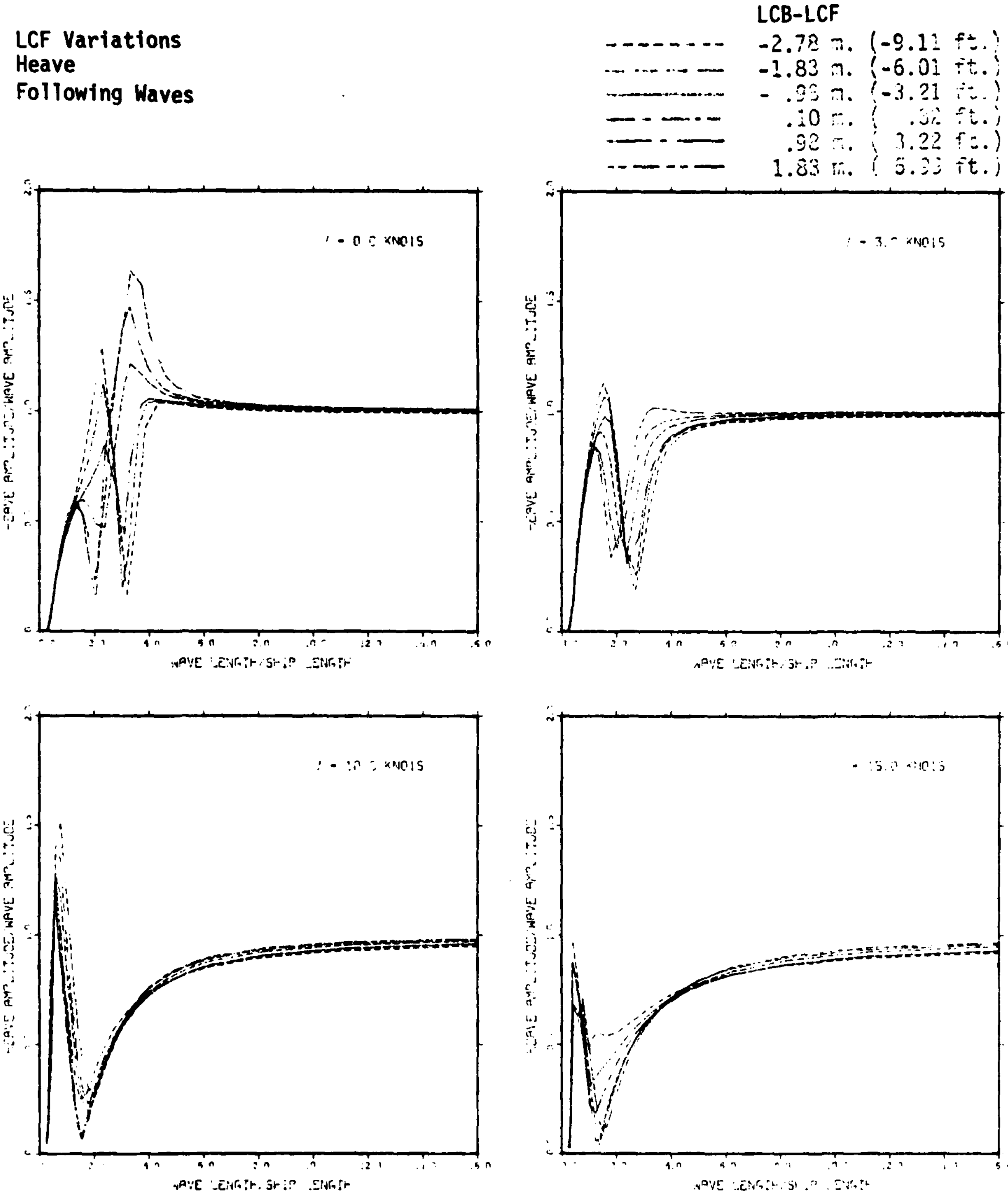

Figure 28 - Heave Transfer Functions in Regular Following Waves for Configurations in the LCF Series

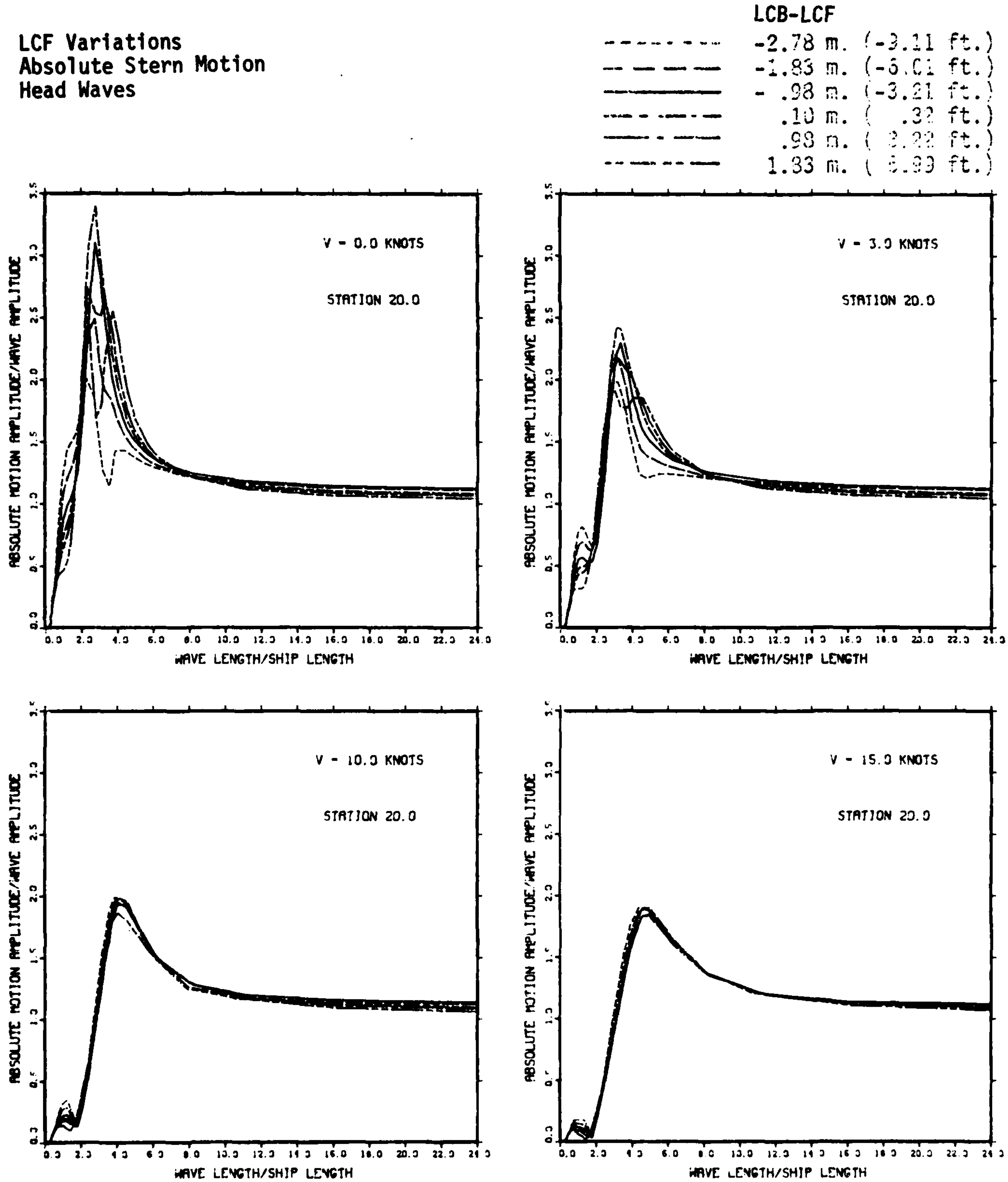

Figure 27 - Absolute Stern Motion Transfer Functions in Regular Head Waves for Configurations in the LCF Series

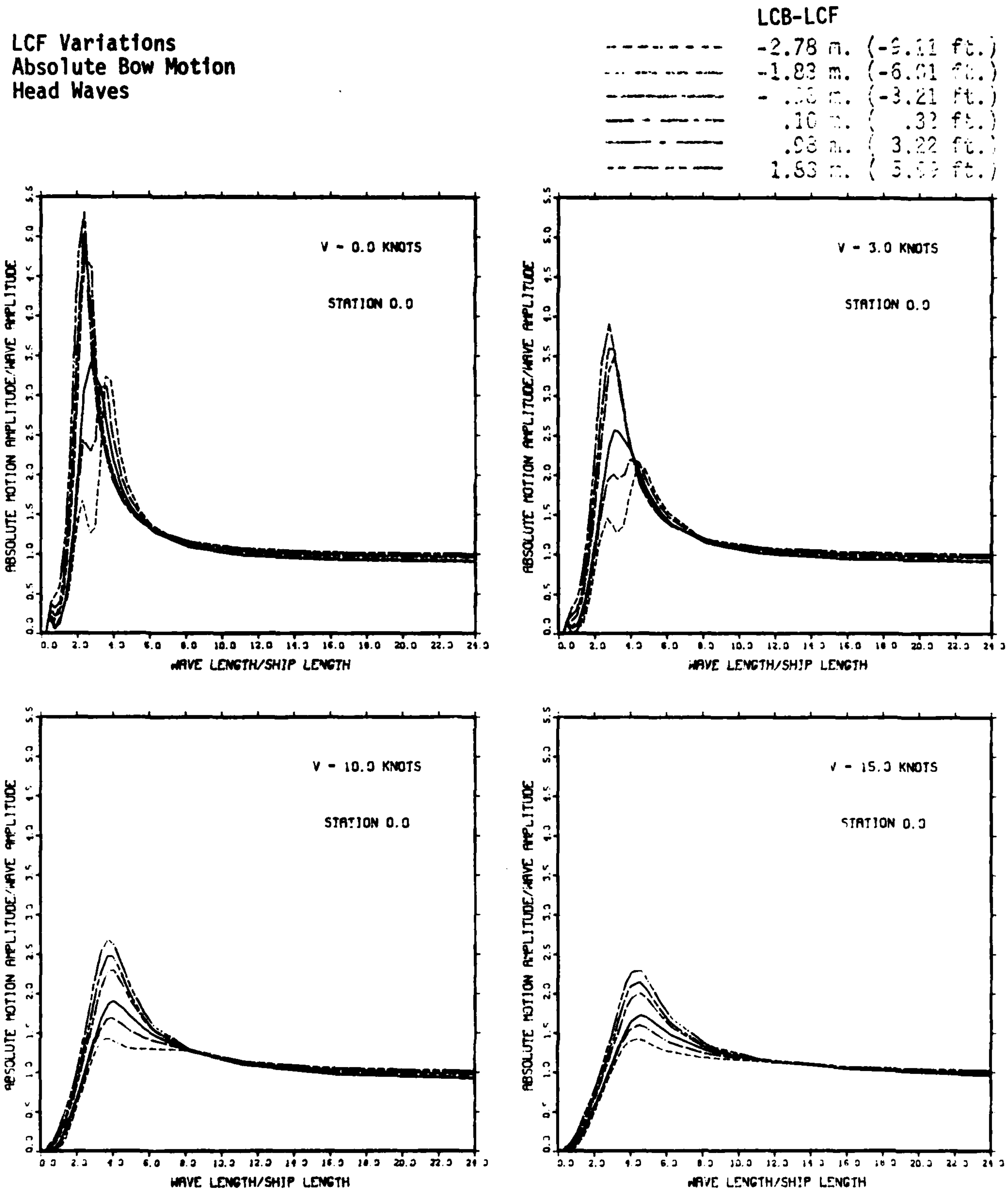

Figure 26 - Absolute Bow Motion Transfer Functions in Regular Head Waves for Configurations in the LCF Series

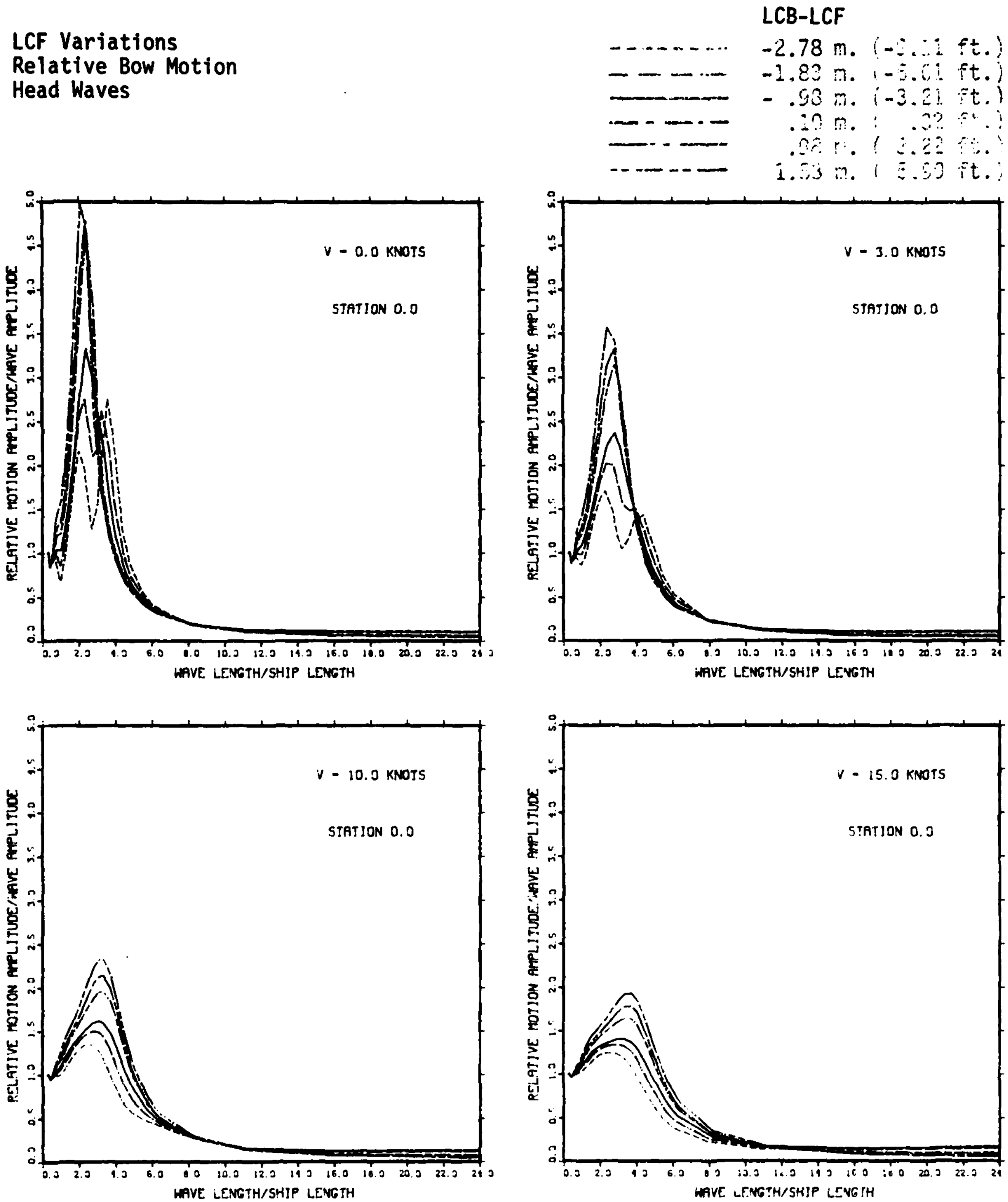

Figure 25 - Relative Bow Motion Transfer Functions in Regular Head Waves for Configurations in the LCF Series

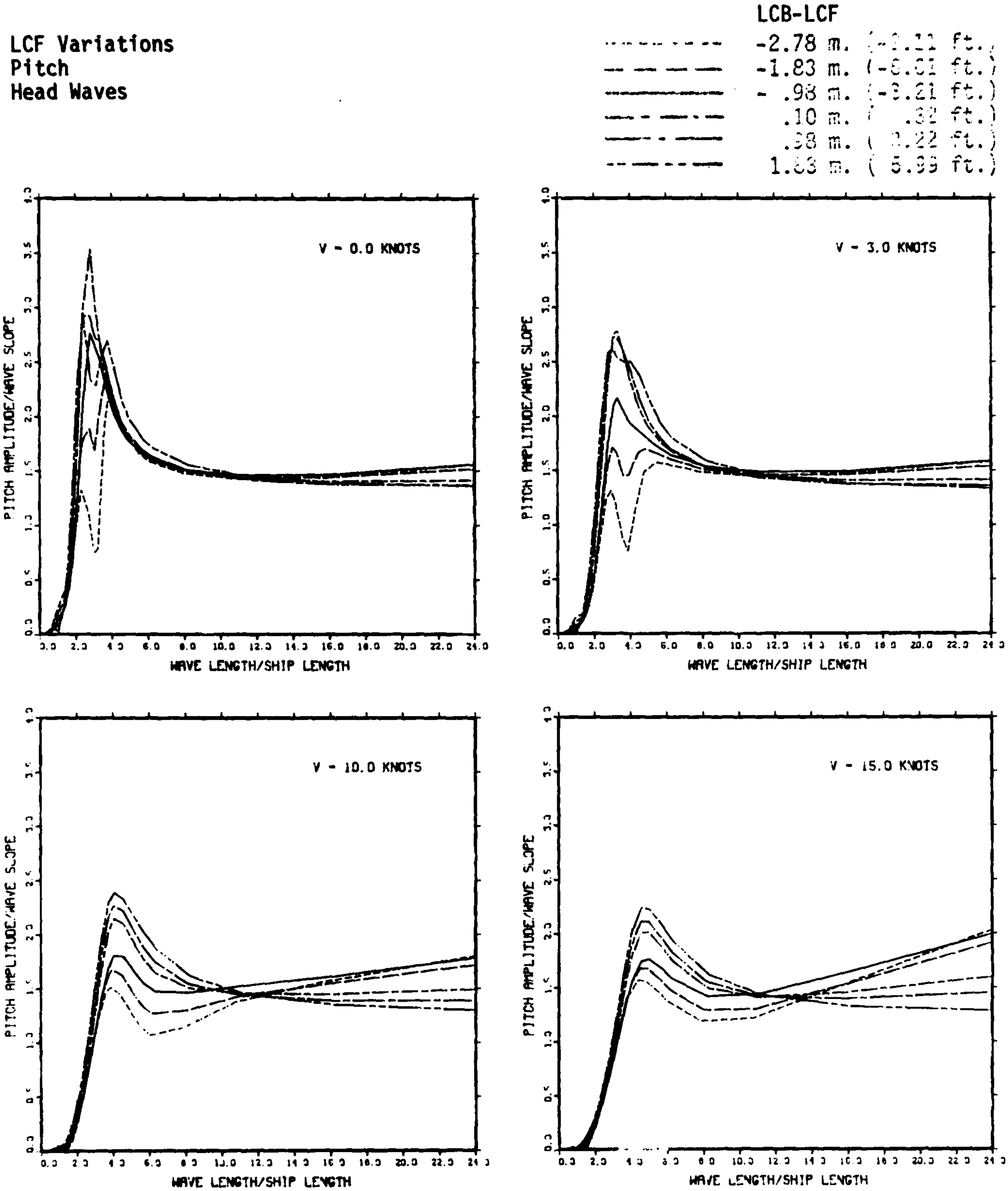

Figure 24 - Pitch Transfer Functions in Regular Head Waves for Configurations in the LCF Series

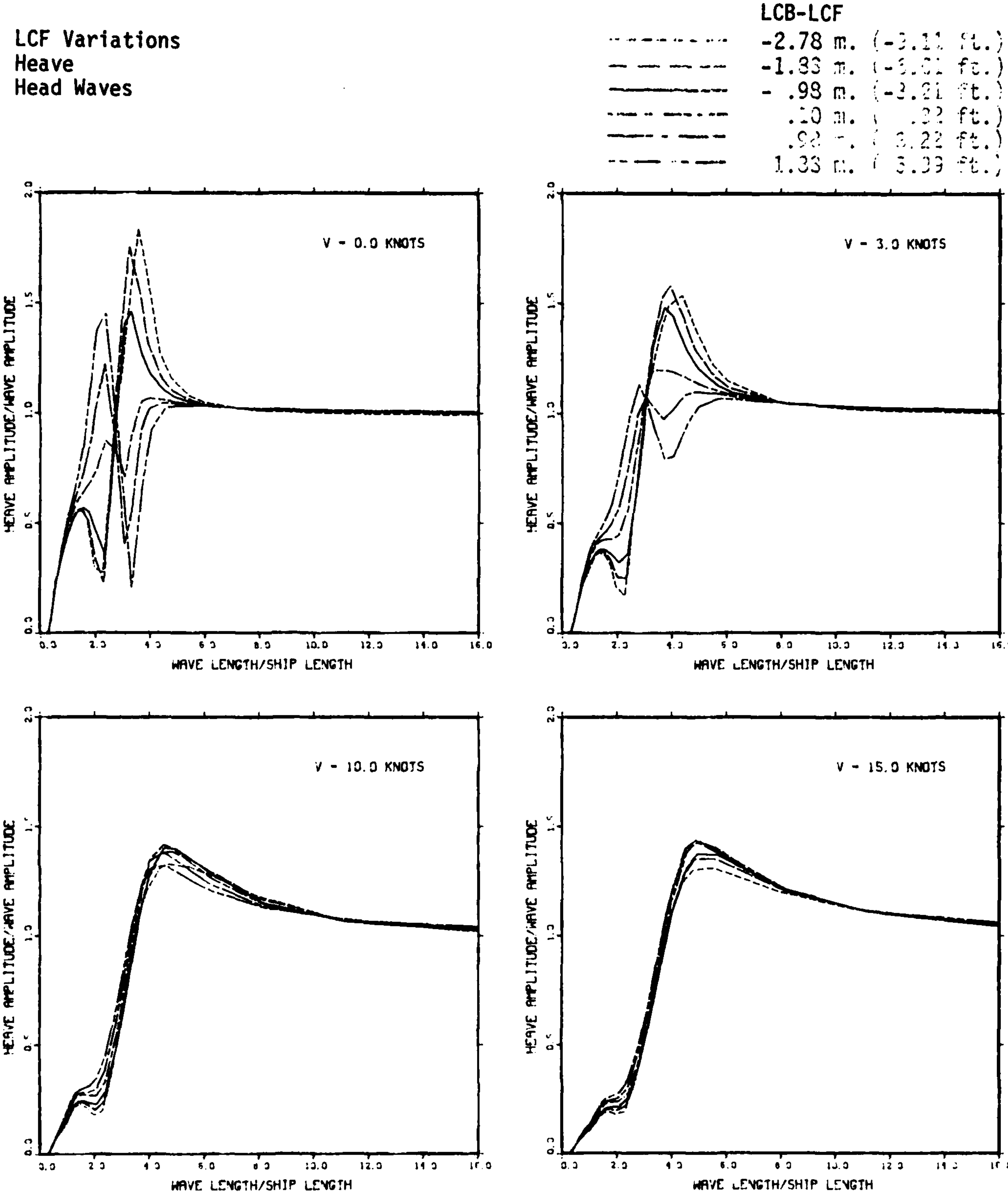

Figure 23 - Heave Transfer Functions in Regular Head Waves for Configurations in the LCF Series

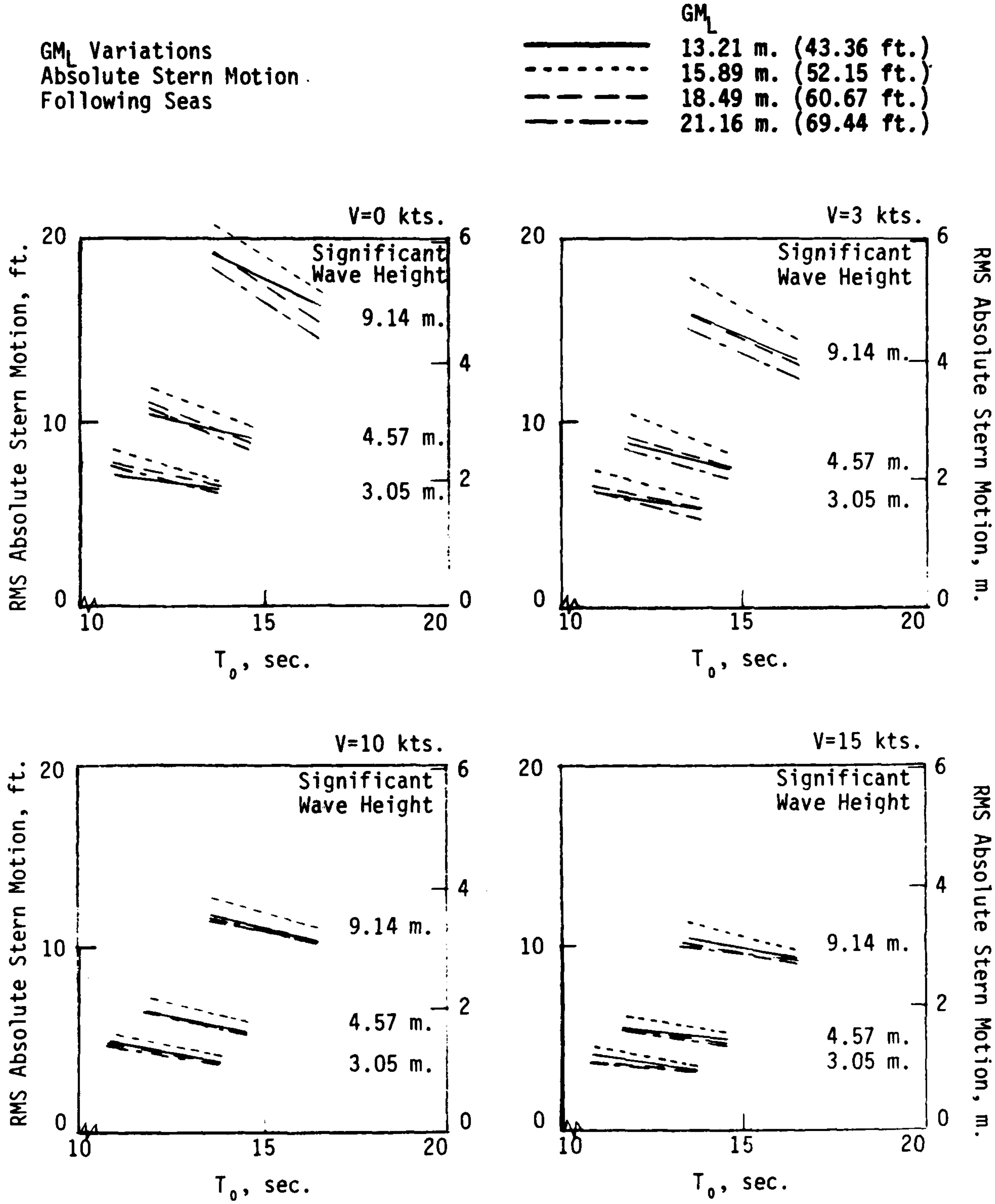

Figure 22 - Absolute Stern Motion RMS Responses in Irregular Following Seas for Configurations in the GM_L Series

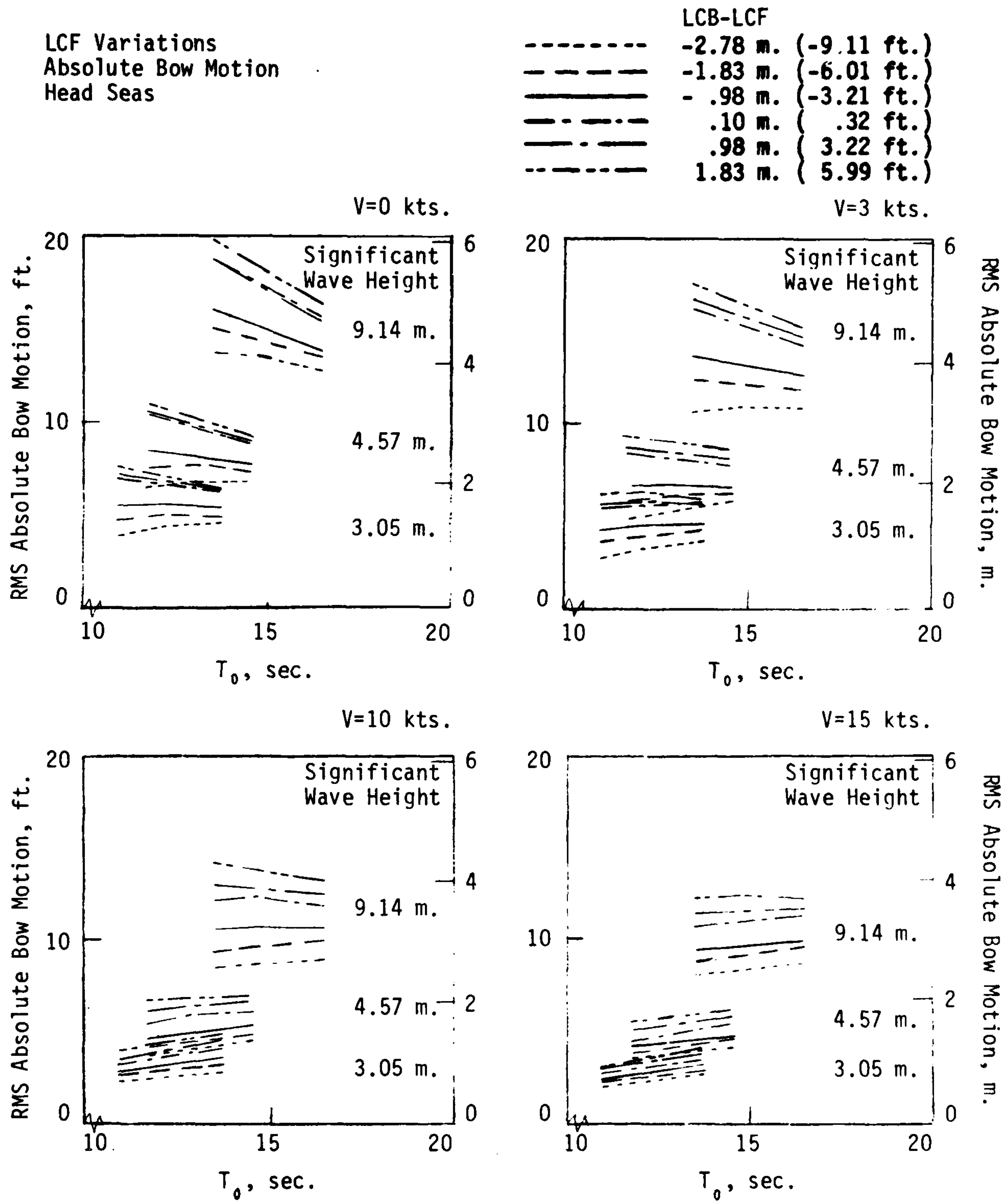

Figure 36 - Absolute Bow Motion RMS Responses in Irregular Head Seas for Configurations in the LCF Series

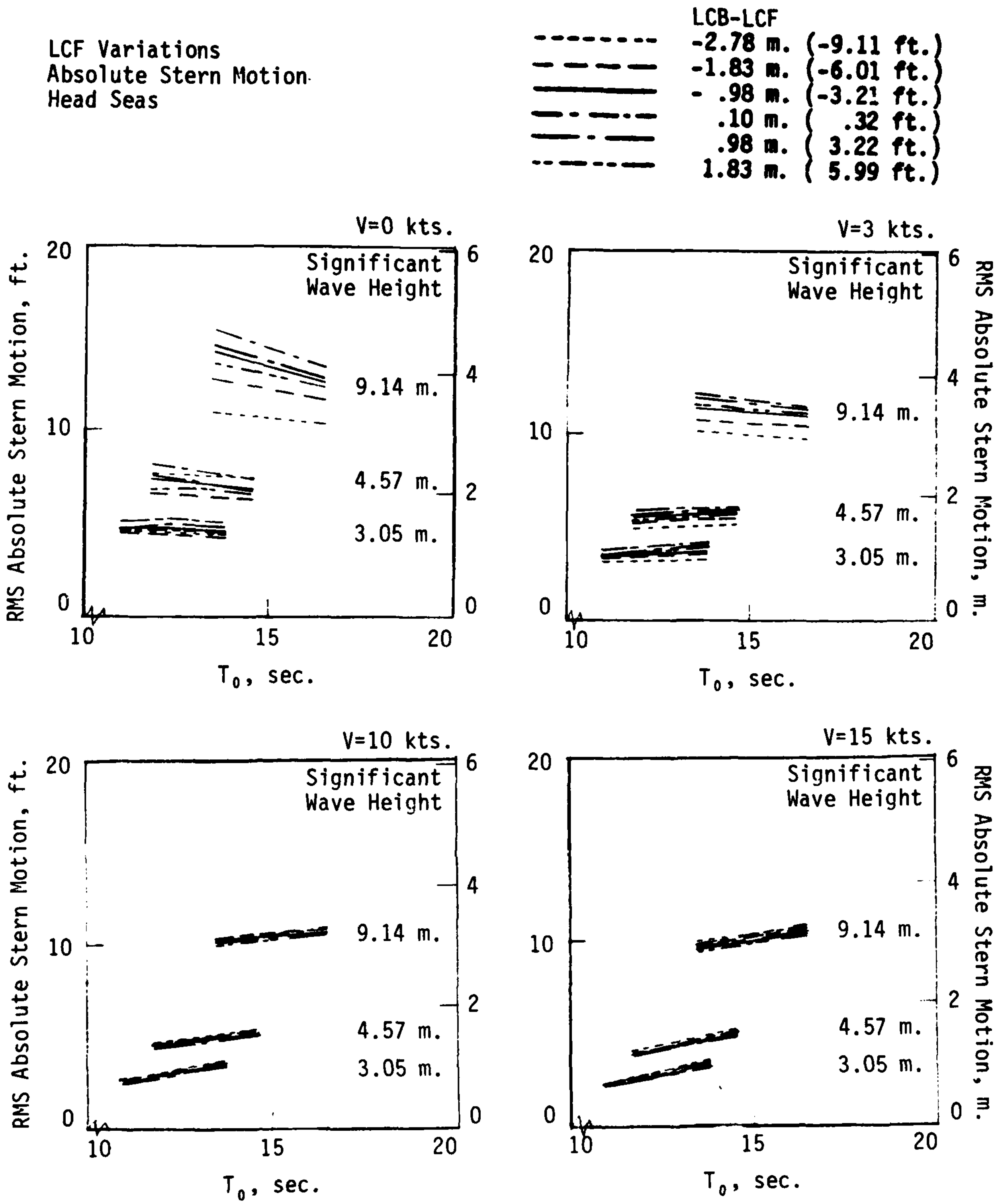

Figure 37 - Absolute Stern Motion RMS Responses in Irregular Head Seas for Configurations in the LCF Series

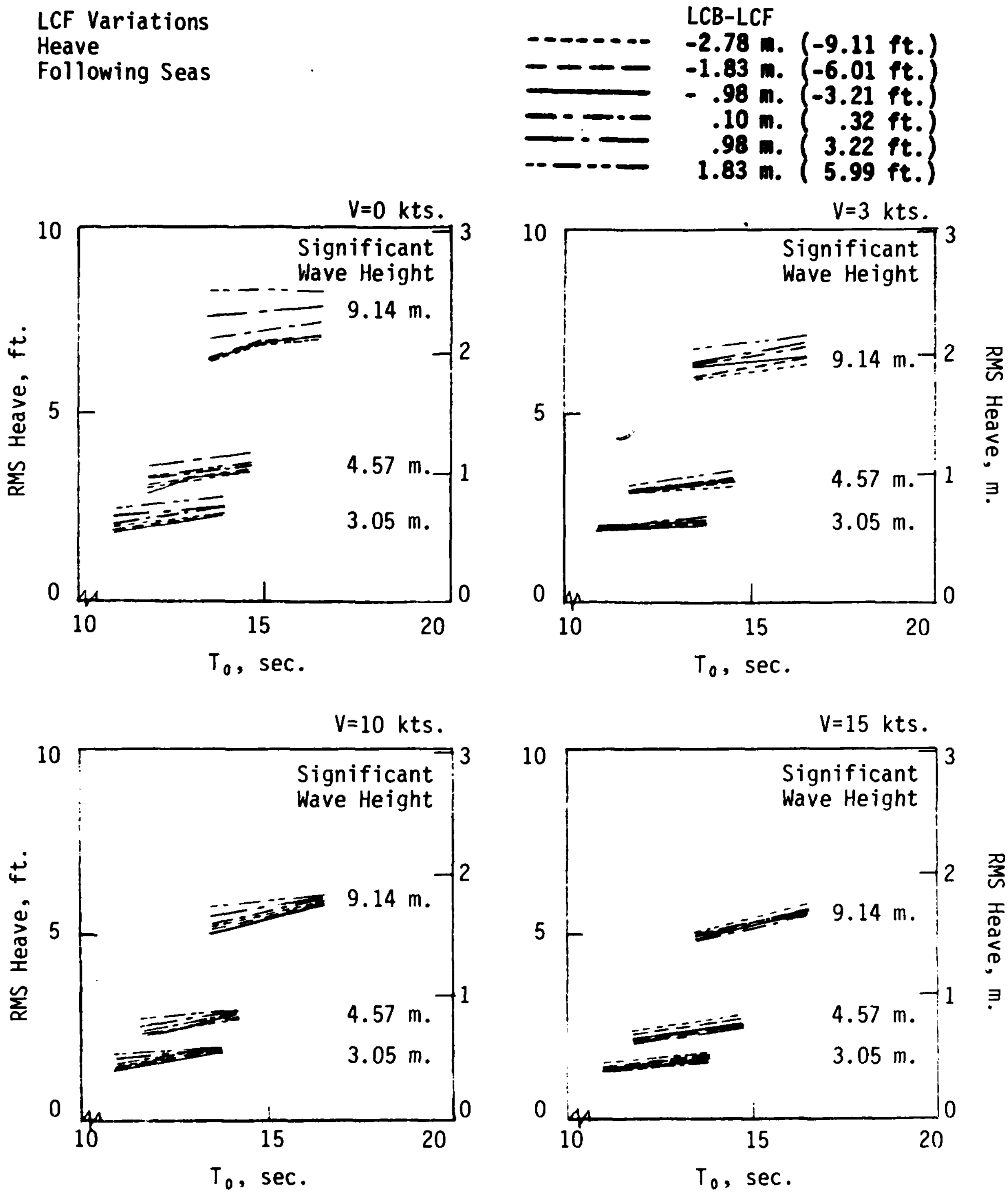

Figure 38 - Heave RMS Responses in Irregular Following Seas for Configurations in the LCF Series

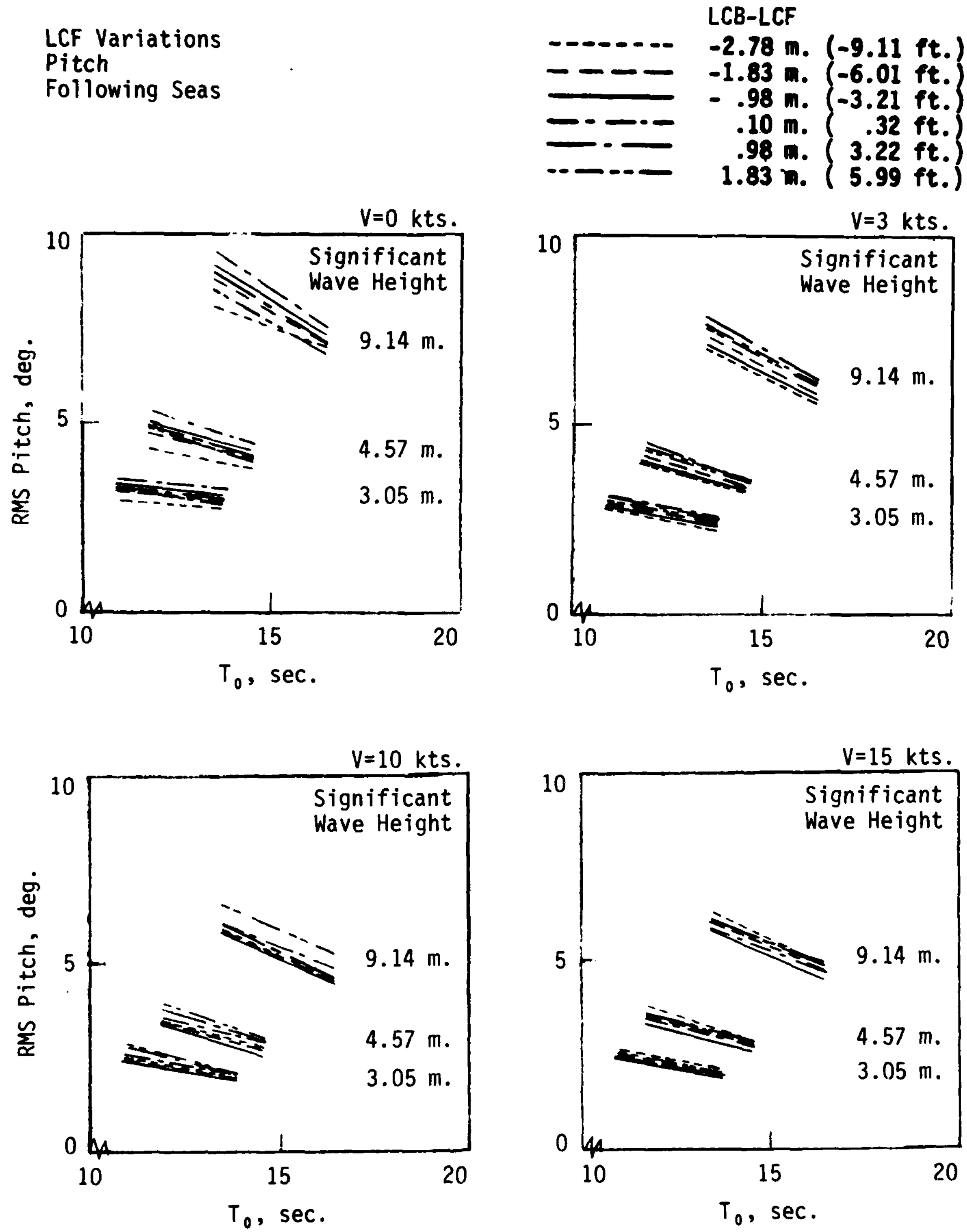

Figure 39 - Pitch RMS Responses in Irregular Following Seas for Configurations in the LCF Series

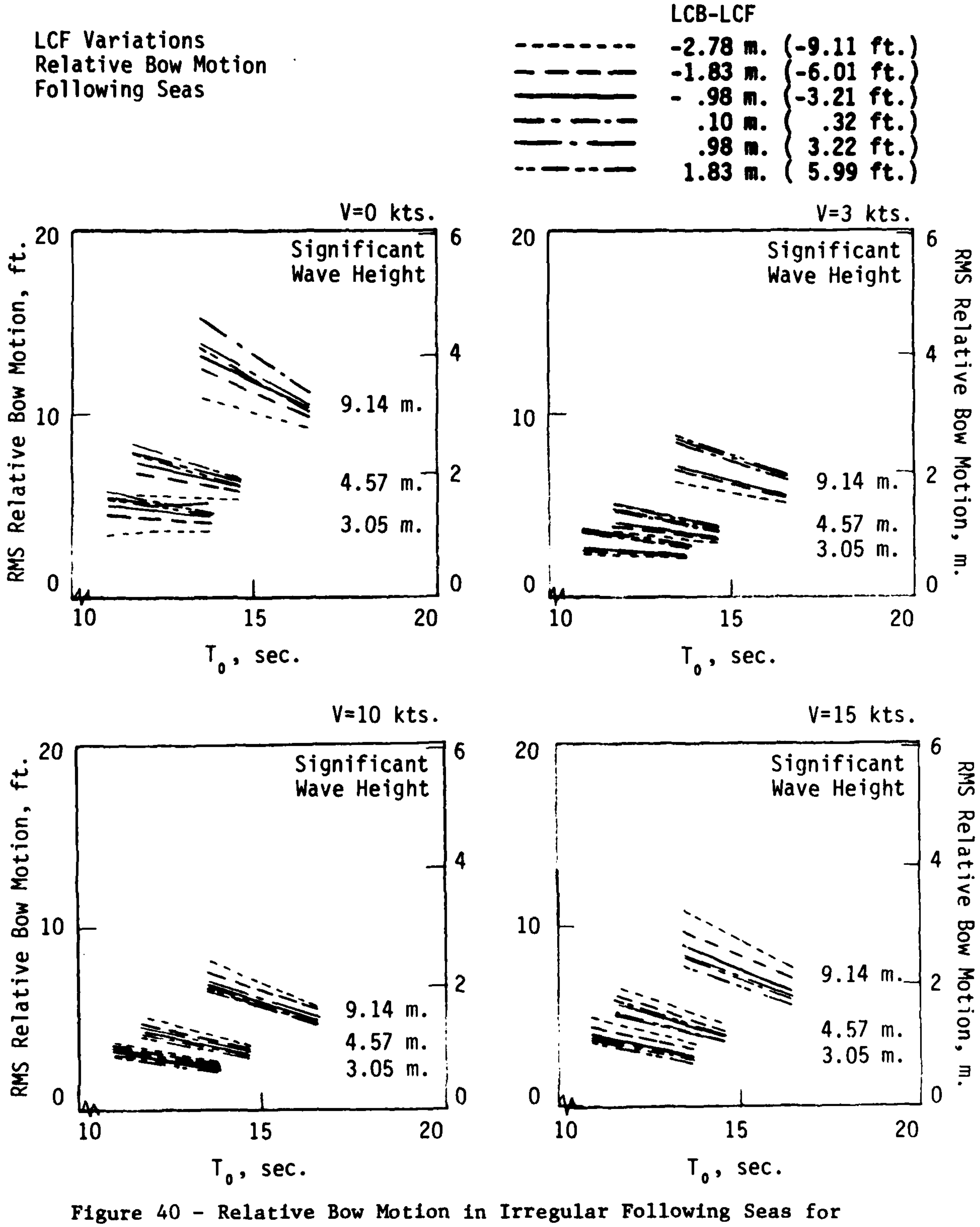

Figure 40 - Relative Bow Motion in Irregular Following Seas for Configurations in the LCF Series

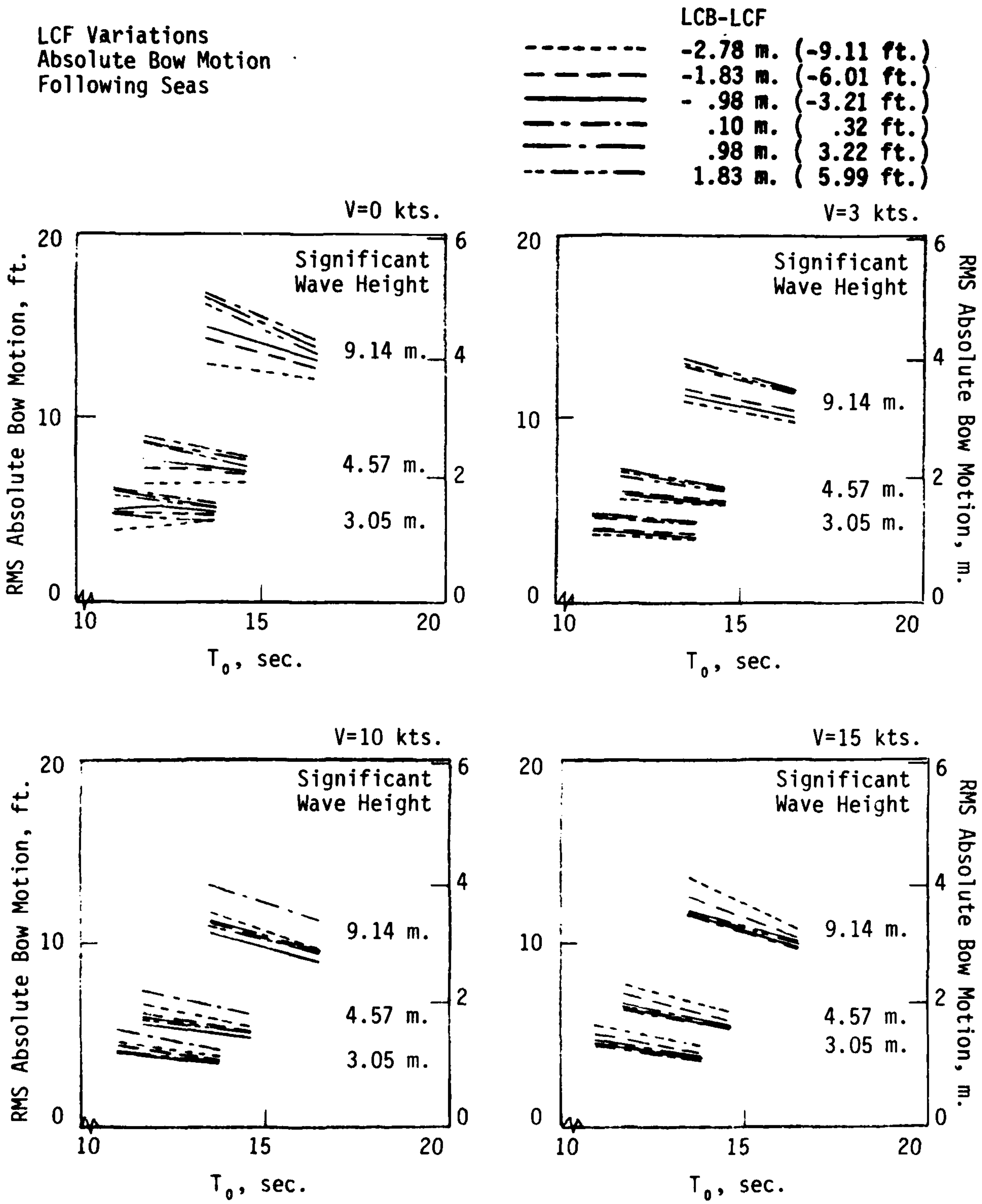

Figure 41 - Absolute Bow Motion in Irregular Following Seas for Configurations in the LCF Series

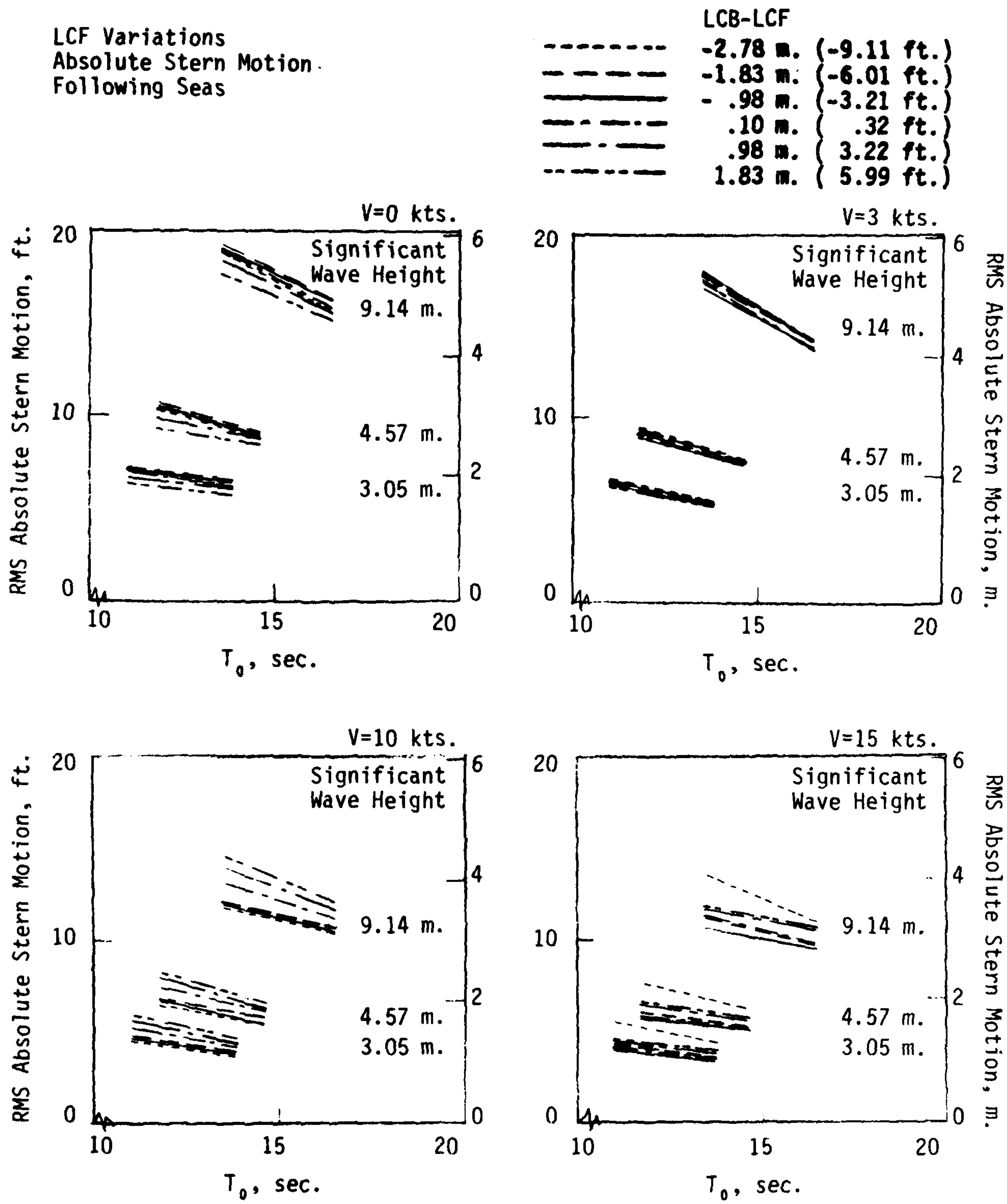

Figure 42 - Absolute Stern Motion in Irregular Following Seas for Configurations in the LCF Series

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